New Mexico Electric Car Challenge

Curriculum

NM Electric Car Challenge – Curriculum

1. Program Introduction

What your team should do this day:

- Brainstorm overall car concepts and sketch them
  - How might your model battery car look?
- How do motors make things move?
  - Find examples of machines, toys, vehicles, etc. with mechanical components
  - Come up with lists of questions that need answers before selecting a design
- If you have more than one team – select number 1, 2 or 3 for each team (ex. Team 1, Team 2, and Team 3)
- Continue brainstorming in class

THE DESIGN PROCESS

You will experience first-hand the process of design. When you design your car, you will start with some ideas in your head and turn them into real-life models that work. Design is different than normal problem-solving because:

- you don't know what the problems are (you discover and solve problems as you go along - everyone's challenges will be different)
- there is never one right answer

Designers have to deal with tradeoffs. For example, when a car designer uses a larger engine for greater performance, it usually sacrifices fuel efficiency. In a sports car, performance and speed are very important. But in a city car, fuel efficiency is more important. So it is up to the designers to decide which goals are the most important to them.

Even though there is no one right answer, some answers may be better than others for a particular application. Obviously, in the Alternative Fuels Challenge Drag Race, the faster cars will win but in the Vehicle Construction Competition, ingenuity will win. But remember, strategy can be a big factor - there are variables like the weather, track surface, or the amount of fuel produced and transferred, that may influence your decisions.

GETTING STARTED

There are informative units on a variety of subjects from how to build the wheels to how the motor works. These units cover the following topics:

- **CHASSIS:** How to build the frame of the car.
- **WHEELS & BEARINGS:** How to make wheels that turn.
- **TRANSMISSIONS:** How to transfer power from the motor to the wheels.
- **MOTORS & POWER SOURCE:** How the motor works.
- **BODY SHELL**: How the shell affects car performance.

In general, when you design, it is good to keep the different parts in mind, but don't worry about the details of each component until you are ready for them.

Each unit will contain 5 sections:

1. PURPOSE
2. IDEAS
3. CONCEPTS
4. MATERIALS
5. EXPERIMENTS AND INVESTIGATIONS

The concept section will raise issues that will help you decide how to make the right decisions and build the winning car.

Experiment as much as possible early on and don't worry about making mistakes. It is always the case with design that you don't know what the problems are until you encounter them. Use what you build for investigations as prototypes for your car to test and evaluate the idea. So get your hands dirty and get started! Good luck and have fun.

2. Design Process

What is design? Design is the process of creating something new to perform a specific function. In this program, students will be given a specific mechanical design problem and asked to create a machine that solves it. To effectively channel creativity, professional design engineers impose a structure on the design process. The process used by many engineers is presented here for teachers and students to use in designing their vehicles.

For more information on each process step, select the process below. The Design Process

1. Define goals and objectives

To begin with, a designer needs to clearly define the problem: what is the **goal** of the design, and what **constraints** exist that will provide limits for the design. Some possible **goals** for the design of the solar car are:

- to make the race-winning model f car
- to make a stylish model car
- to make a sturdy, robust car

Constraints are the limitations that are imposed upon the design by the designer or by the problem itself. In designing a model solar car some **constraints** imposed by the designer might be:

- Materials will cost less than $20 and be easy to find
- The car must be constructed in 8 weeks

In addition, there are **constraints** imposed by the rules, such as:

- The car must be within the specified size limits;
- The car may use only certain materials.

Defining the goals and constraints helps focus the designer's time and effort on the most important areas.

2. Generate ideas

Design relies on generating ideas. **Brainstorming** is an effective idea-generating technique that is usually done in groups. The goal of a "brainstorming session" is to generate as many ideas as possible in the given time. Groups often include individuals with varied backgrounds to get as many perspectives on a problem as possible.

The duration of brainstorming sessions varies with the quantity and complexity of the issues to be discussed, but for a student group such as this a session lasting from 15 to 30 minutes is recommended. Students can begin with brainstorming ideas for car components.

Some possible topics for **brainstorming** sessions are:

- Types of transmissions
- Ways to attach battery to the car
- Aerodynamic body shapes
- Materials for wheels, axles and bearings

To make these sessions productive, it is useful to set a few rules beforehand. One of the most important is "There is no such thing as a dumb idea." Participants are encouraged to contribute ideas they consider silly since these ideas may trigger more practical ones in their own or anther participant's thinking. Another useful rule is "No one may interrupt the person who is speaking." To ensure that everyone gets a chance to contribute ideas, the leader may consider breaking the class into smaller groups and sharing the results of the individual sessions. Students should sketch their ideas as much as possible, or otherwise record them clearly.

For an effective session there should be both a **leader** and a **scribe** (the mentor or teacher can serve as one or both). The leader's role is to keep the discussion from getting off-track and maintain order in the group. The scribe's job is to record all ideas that are generated. He or she is permitted to stop the session to ask for clarification of an idea (or for a participant to draw a concept), and should compile the notes for future reference.

Students can also generate ideas outside of brainstorming sessions. A skillful designer combines new ideas with existing ones, or combines existing ideas in innovative ways. To stimulate the generation of ideas and to increase the awareness of existing technologies, related mechanical devices (such as toys and small appliances) should be examined by the students. How did other designers solve problems similar to those in model solar car design (wheels, bearings, transmissions, chassis, etc.)? What parts can be used or where can similar parts be found? Reference books such as "The Way Things Work" by David Macaulay or user's manuals for various appliances may be consulted for ideas. Trips to hardware stores, hobby shops, craft stores, etc. to look at various tools and gadgets are also good ways to get ideas. A good designer sees to it that he or she has a wide variety of ideas to choose from.

3. Investigate ideas

Once ideas have been tossed around, students will be wondering how to choose between all of these concepts. Students are encouraged to formulate questions and experiments that will help to answer them. There is a natural tendency to go for the ideas the one likes best, or has a "gut" feeling for. These concepts may indeed be the ones that work out best, but unless they are tested against other concepts, the designer can never be sure that all ideas were investigated fully and the best design was selected. There are many ways to investigate ideas, such as research and consulting with "experts", but the most direct and convincing way is to try it out for oneself. This is the essence of hands-on design. Often the design is broken down into smaller problems which are investigated individually. In the case of a model battery car, the "smaller problems" are the individual mechanical components (wheels, transmissions, chassis, etc.).

Some possible investigations are:

- What are good ways to build wheel axles and bearings?
- What is the effect of weight on a vehicle?
- How can a simple transmission be built from low-cost parts?
- What car body shapes have the lowest aerodynamic drag?

The investigations called for here are likely to be simple experiments where students get a feel for the mechanical concept behind their question. A complex investigation may be broken up and assigned to different groups or individuals; their results can later be shared with the entire class. A student investigating materials and methods for building a car chassis, for example, may take simple pieces of each material and watch how they react to various loads or forces. Another example may be to build various transmissions on a simple chassis (not necessarily the one they intend to use in their final car) and compare their relative performance and ease of construction.

As part of this process, students should identify design variables, that is, attributes which can be varied to affect performance.

Some of those **design variables** are:

- transmission ratio
- wheel diameter
- vehicle shape
- material selection

The goal of these investigations is to gain an understanding of all the individual parts of a vehicle. The groups will probably have a few concepts for each component; they will be narrowed down in the next phase.

4. Compare concepts and select a design

Designers are comparing concepts or doing "trade-offs" of alternative component designs throughout the design process. They weigh the various ideas against the design criteria and see which one(s) come out best. Much of the time the designer does this in his or her head. However it is often helpful, especially when working with a group or a complex problem, to write down the pros and cons of each idea. Some examples of **pros and cons** for a particular transmission design (a gear drive in this case) are:

Pros	Cons
• Reliable	• Harder to build and align properly
• Won't slip	• Harder to find meshing gears
• High efficiency	• Harder to modify ratio

In addition to presenting all relevant information in a single place, the record of ideas also allows the designer to go back later and choose another design if the first one selected does not work out. Once designs of individual components have been evaluated and one or two leaders identified, students can begin to integrate them into a complete car design. The design for the complete car will be a combination of the students' most workable components. The deciding factor in the choice between two or more workable options for a particular component may be its compatibility with the rest of the car's design. If concepts generated thus far are not sufficient, it may be necessary to refer to brainstorming notes and/or generating more ideas.

5. Build

This is the step where the design becomes a reality. Your design should take into account the materials and tools required to produce your car from them. Be sure and use proper safety procedures and equipment when working on your car and remember that it must be able to stand up to the rigors of racing. Thorough prototyping of components helps the final vehicle construction go smoothly. Parts built for experimentation may also be used in the final car design and construction.

Building usually takes more time than you think, especially if students are not familiar with the materials. The teacher/sponsor and mentor should ensure that there is adequate time and supervision for the build sessions.

6. Test

Once a car is built it needs to be tested to see if all the components are working together to accomplish the goals and meet the constraints placed on the design. Setting up measurable tests is an important part of the design process so that as adjustments are made to the car or its components the designer can determine if the change was beneficial or detrimental. If you find a major problem during testing you can return to the generate ideas step or look at some of the options you had during the compare and select step.

The testing phase is an appropriate time for the class to discuss performance measures. Some **performance measures** for the complete car include:

- Time to go 10 meters
- Rolling resistance and Aerodynamic drag
- Total vehicle weight
- Acceleration
- Top speed

A long hallway or track and guide wires are useful for vehicle testing. Since hydrogen power may not always be available for testing the vehicle, alternative power sources will be required.

Teachers/sponsors or mentors may need to help students mount batteries to their vehicles. A ramp may also be set up for "roll down" tests (motor must be disconnected from transmission for this test) to test rolling resistance and aerodynamic drag.

Intermediate contests based on one or more of these attributes may be held to identify leading designs. The winners can be decided on the basis of relative performance of multiple cars.

7. Optimize

Optimization occurs after the car has been assembled and tested. This is the process of fine-tuning the design for top performance. The winning car in this contest is likely to have optimized the design variables, that is, chosen the best ones for the given task. This is not always straightforward. Experienced designers know that this process involves trade-offs, because optimizing one variable may prevent you from optimizing another.

For example, a frame that is both stiff and light may be desired, but stiffer frames may be heavier. Another classic example is the transmission ratio: a car with high top speed takes a long time to accelerate. Taking the time to optimize the car will often improve the performance dramatically.

Remember that as components are optimized the car must be tested again to see the overall effect of the change. This will return you to the test step of the process and requires measurable testing to compare.

8. Final Product

The final product of all your hard work is ready. You may find that on race day you can make adjustments to your vehicle between races. But remember when you are called to the line for a start, you have to report - the race will not wait for you to make adjustments and you may have to forfeit.

Think through the possible adjustments you will need to make and prepare for them as you go through the steps just completed. Make sure everything is ready by testing all your designs. Now Lets Go Racing!!!

The process presented here may be used at any and all levels of model car design, from the design of individual components to the complete car as a system. The key principle in the process is to start all designs with many ideas, then investigate and evaluate several of them before locking into a design.

Part of the challenge in design is learning to combine good ideas from several people into a winning design. Students should be encouraged or required to use a notebook to record their ideas and sketches. Ideas not written down or sketched are quickly forgotten. In addition to providing a means to store and communicate ideas, putting thoughts down on paper often aids in idea generation and clarity.

3. Chassis

1. PURPOSE:

The car's chassis is its frame. It holds all of the main components, or parts, together.

2. IDEAS:

Some possible ideas for a solar car chassis are shown below. Try different ideas. Try different materials.

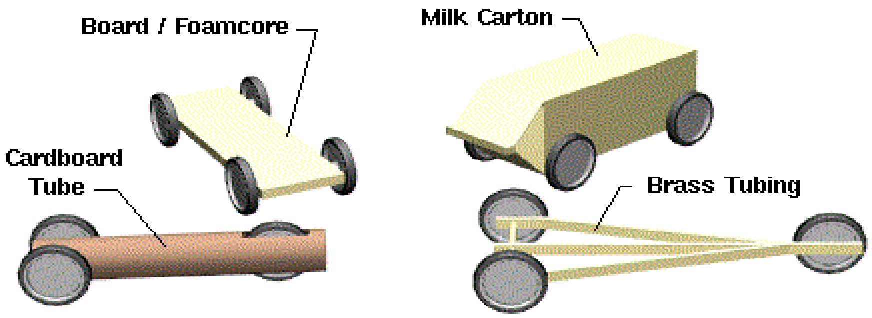


Figure 1: Examples of Chasssis

3. CONCEPTS:

a. ***Weight and Stiffness***

One thing you will discover when you build your car is that designing and building involves tradeoffs. There is no one ideal design. This is true with the chassis of your car.

One obvious consideration is that you don't want your car too heavy. It is easier for your motor to push a light car than a big, heavy one. In battery cars, efficiency is very important, and you don't want to waste energy.

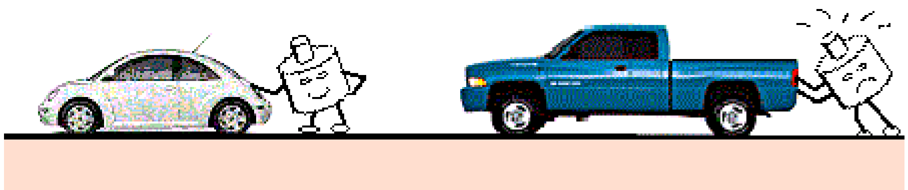


Figure 2: Weight affects ease of movement

But something you must also keep in mind is that a light car can be pushed easily by wind, too. Even if the wind does not blow the car over, it may make it harder to go in a straight line. (This depends not only on the weight, but on where the weight is, and the shape of the body, too. We will talk more about the body and aerodynamics in a later section.)

b. ***Materials***

In most cases it is more difficult to make the car light enough (you can always add a little ballast, or weight), so in this section we will emphasize lightweight materials and construction. The first step to a lightweight chassis is in choosing the right materials. Balsa wood, for example, is a commonly chosen material because it is lightweight. But more importantly, is fairly stiff for its weight.

What is the difference between strong and stiff? Strong means it will not break easily. Stiff means it will not bend easily.

Figure 3: Strength verses Stiffness

For the car, stiffness is very important. Stiff, light materials include styrofoam, foam core, balsa wood, corrugated cardboard, and some plastics.

c. ***Shape***

Some heavier materials are also appropriate if they are constructed correctly. Try the Investigation below to investigate how the shape of a material can affect its stiffness.

Engineers can stiffen flexible materials using shapes or use less of a heavier material with just a change of shape. Look at a cardboard box. Why is the inside corrugated?

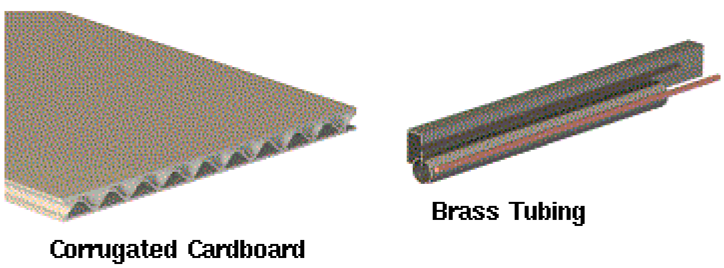


Figure 4: Examples of stiffening by shape

Other materials are made stiffer or stronger by sandwiching them between other materials. Look at foam board and plywood.

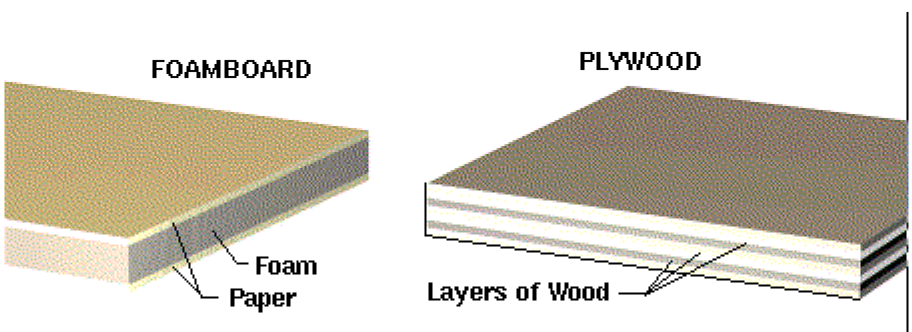


Figure 5: Examples of stiffening by Layering

d. ***Orientation***

As you saw with the folded pieces of paper, orientation is also very important in determining stiffness. Try the investigation below to see how the orientation of the material affects its stiffness.

Imagine you wish to stiffen your chassis by adding ribs. You glue two strips of material to the bottom of the chassis as shown in figure 6 trying to strengthen to the chassis.

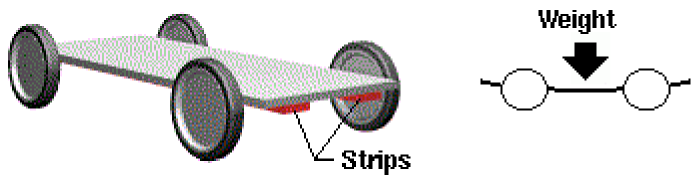


Figure 6: Stiffening chassis by layering

Unfortunately, that didn't seem to do the trick - the chassis still sags. Your partner insists that adding strips of material will help, but you know that this is not necessary. You have a better idea! What is your idea?

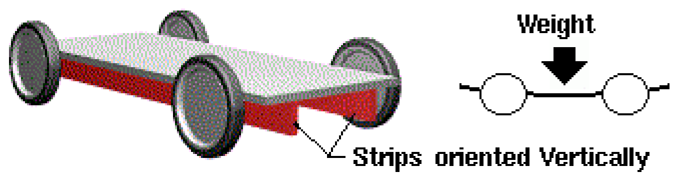


Figure 7: Stiffening chassis by orientation

Well, if you turn the strips sideways, as shown in figure 7, you add the weight again and your chassis is much stiffer...without adding much material!

So, as you can see, if you are smart about your material selection, and you remember the importance of shape and orientation of materials, you will have much more control over the weight of your car.

4. MATERIALS:

Any material that is light and stiff would be appropriate. Some hollow tubing is very stiff for its weight. Arts and crafts stores, hobby stores and hardware stores are good sources. Some stores have scrap materials like cardboard. Or, look around your house for scraps. Some materials we found are useful are:

- Stiff insulating foam board
- Foam core board
- Balsa wood
- Brass tubing
- Cardboard tubes
- Shoe box
- Soda bottle
- Rigid plastic
- Corrugated cardboard
- Plexiglass

5. EXPERIMENTS & INVESTIGATIONS:

Structures Investigations

Materials Needed:

- 2 - 1" dia dowels or sticks
- Sheet of ordinary paper
- Sheet of ordinary cardboard (1/16" thick)
- Sheet of corrugated cardboard
- Sheet of Foamcore board
- Plastic sheets
- Small weights (up to 1lb)

Procedure: (see Figure 8)

1. Place the dowels about 6" to 8" apart.
2. Place the various materials across the dowels and place weights at various positions.
3. What positions do the weights have the least effect on the shape of the material?
4. Try two thicknesses of the same material and repeat the application of weights.
5. Is the extra strength worth the added weight to you? Can you combine materials to achieve the desired performance?
6. Vary the shapes of the materials by folding into a U or a fan (keep the size and weight of the material constant) and repeat the application of weights.
7. What effect does folding have? Does direction matter?
8. Try the corrugated cardboard with ribs running across and with the dowels.
9. Why is corrugated cardboard used more frequently for things than the same thickness of simple cardboard?

Heavy paper can also be used and shapes can be produced using scissors, tape and/or glue.

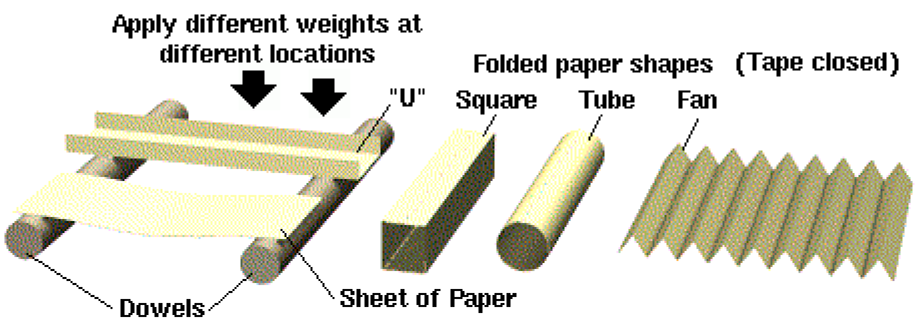


Figure 8: Stiffness investigation setup

Observations:

The dowels or sticks represent your axles and wheels and they allow the materials to flex and bend much as real wheels and axles do with the chasses of the car. The differences in the loads that a miniature car frame can carry with materials of different strength and shape are demonstrated here. Use this type of test to evaluate the materials you are considering in the design of your car.

Orientation

Materials Needed:

- Plastic or wood ruler

Procedure: (see Figure 9)

1. Take the ruler and hold it at each end.
2. Try to bend it in both directions - across thin and wide.
3. Which way does the ruler bend more?
4. Do not bend the ruler so far that it breaks.

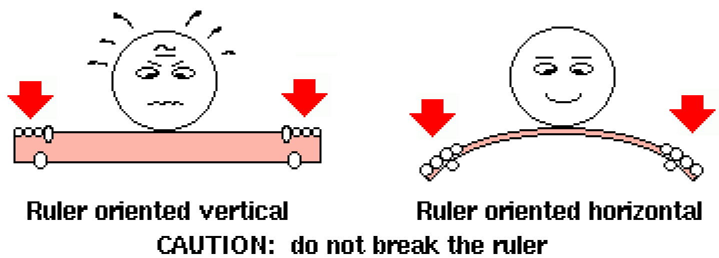


Figure 9: Orientation investigation setup

Observations:

The ruler will bend more in the thin direction. It bends very little in the wide direction.

4. Wheels, Axles, & Bearings

1. **PURPOSE:**

Wheels support the chassis and allow the car to roll forward. Bearings support the wheels while allowing them to rotate.

2. **IDEAS:**

Wheels can be large, small, narrow, or wide...here are some ideas to start you thinking.

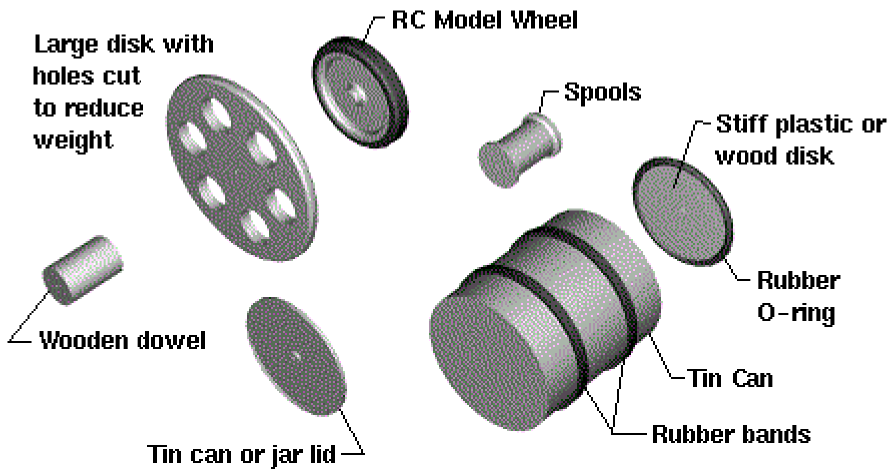


Figure 1: Examples of wheels

3. **CONCEPTS:**

a. ***Friction***

Friction keeps things from sliding against each other. When you build your cars, there are some parts you want to slide easily, and other parts you do not want to slide at all.

b. ***Tire Traction***

When you have two things that must roll against each other, like a wheel rolling along the road, friction keeps them from slipping. The type of friction is also called "traction," and is important to remember when building your wheels.

Why do mountain bikes have big, fat, knobby tires? If you have to bike up a muddy hill covered with leaves, your tires will slip if they don't have enough traction. And the big knobs of rubber can grip onto the dirt and rocks and keep the tires from slipping on

Figure 2: Mountain Bike

(Another reason for the thick tires, too, is because they are more rugged and can take the abuse from the trail!)

Now, the question is, why don't racing bicycles have fat, knobby tires if these wheels have good traction? Once again, there is a tradeoff in designing a wheel.

Mountain bike tires have two main disadvantages. The first disadvantage is the thick, knobby rubber tire that gives them such great traction also makes them inefficient. Every time a rubber "knob" is compressed and bent by the road, energy is lost. Where does this energy go? If you have ever felt an automobile tire after it has been on the road, you probably noticed that it was hot. The energy it took to compress the rubber and air in the tire was lost to heat.

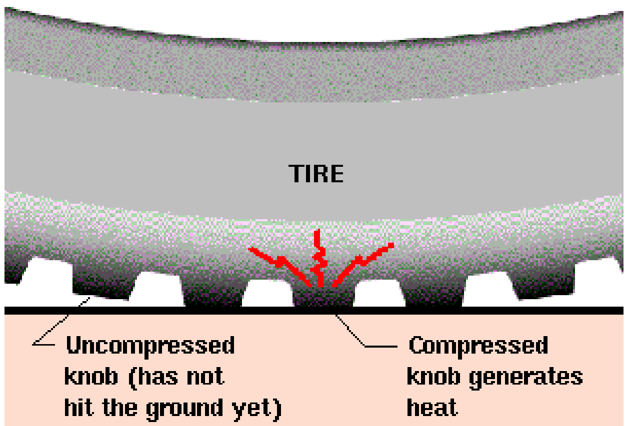


Figure 3: Knobs on a Mountain Bike Tire

The other main disadvantage of mountain bike tires is their weight. Weight in tires is actually more difficult to move than weight in the chassis. Weight in the chassis has to be moved forward, but the weight in the wheels has to be moved forward and around the circle. The heavier the wheel, the more energy it takes to get the wheel turning. Surprisingly, the bigger the wheel diameter (even if it is the same weight), the more energy it takes to get the wheel turning.

Figure 4: Racing Bike

So, racing bicycles do not have mountain bike tires, because traction is not as important. But what is important is efficiency, so that the bicyclist does not need to expend a lot of energy. The bicycle designers have made a conscious decision to use different tires designed for efficiency and not traction.

c. ***Weight Distribution & Traction***

Imagine your rear-wheel-drive car has trouble -- its back wheels are slipping. Your partner suggests adding some rubber bands around the wheels to increase traction, and you agree. The rear wheel still slips some. Your other partner wants to add some weight to the car, like this:

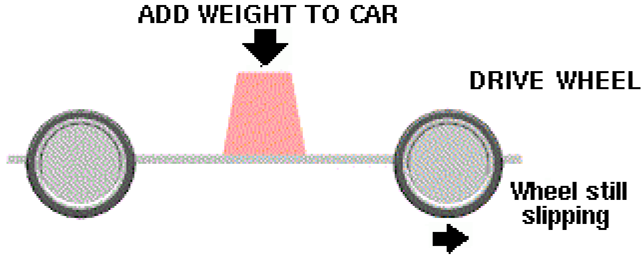


Figure 5: Adding weight to middle of car

But it does not work. You tell him you have a better idea. You move the existing weight, and now it works! Why?

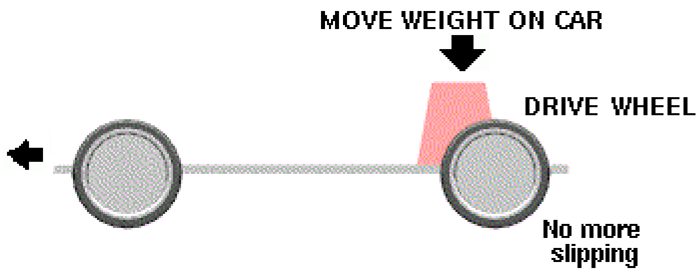


Figure 6: Move weight over drive wheel of the car

Remember that all of the force is transmitted through the driven wheels, so the moved weight increased the traction where it was needed. Weight distribution is very important, since you can increase traction just by moving existing weight from one part of the car to the other.

Have you ever heard that front wheel drive cars are better in snow and ice than rear wheel drive vehicles? Front wheel drive cars aren't heavier. But the engine is very heavy and is located above the front wheels. This helps traction in front wheel drive cars because the weight is right above the driven wheels.

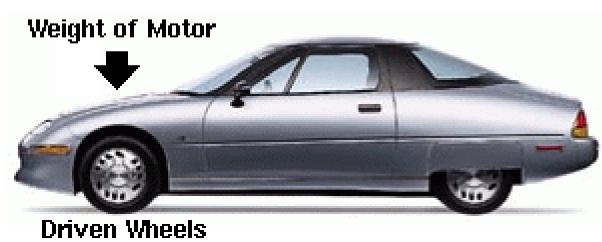


Figure 7: Front Wheel Drive weight distribution

So, in summary, traction is important for transmitting the forces from the wheels to the road. If any of your wheels are spinning rather than rolling, you probably need more traction. Traction can increased by adding a non-slip material around the wheels (like a tire) or, by moving weight over the driven wheels. But, remember, it is also important to have efficient wheels, which are usually thin and lightweight.

d. ***Axle***

The axle is the component on which the wheel turns. It must be strong, straight and polished to reduce friction losses. Is a smaller diameter axle better? Why do "Hot Wheels" toy cars have such tiny axles and go so fast and far? The larger the diameter of the axle the farther away from the center they contact the bearings. Like a book dragging on the table all the way out at the corners, a large axle will be harder to turn.

e. ***Axle Bearings***

When you have two things rubbing against each other but you want them to move freely, you will have to consider the amount of friction. Friction slows things down and wastes energy. For example, try sliding a coin and an eraser across the table. The reason the coin slides much more easily is there is less friction between the coin and the table than there is between the eraser and the table.

One case where friction is very undesirable is in the wheel axle. The axle must be supported and attached to the chassis, but still must be able to turn. Components which allow the relative motion of two parts are called bearings. Some ideas for bearings are shown in Figure 8.

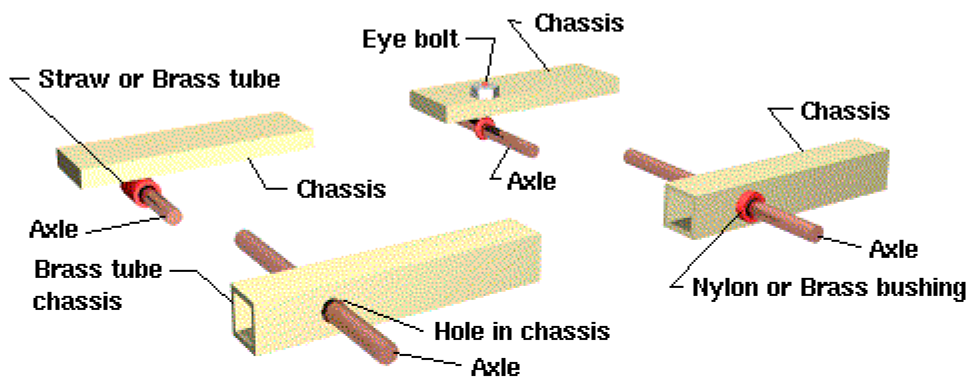


Figure 8: Examples of Bearings

Look at a bicycle or a roller blade. Hold it above the ground and spin one of the wheels. Between each wheel and its center axle is a type of bearing called a "ball bearing." The bearing holds the wheel on the axle, but reduces the friction between them, so the wheel can spin for a long time without slowing down.

Choose axle and bearing materials that have low friction against each other. Surface finish is critical. Make sure all the running surfaces are as smooth as possible.

f. ***Thrust Bearings***

These are whatever keeps the axle from falling out the side of the car. If the edges of the wheels rub on the body they will have a lot of friction (See Figure 9). If there is something around the axles that let the center portion of the wheel touch first, the friction will be lower.

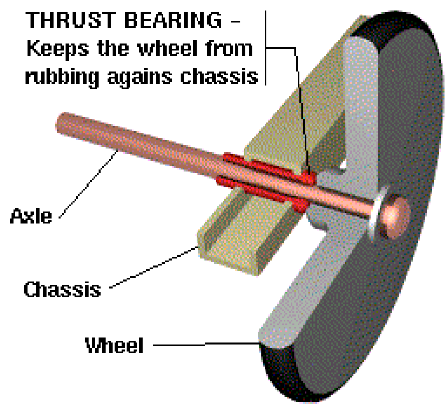


Figure 9: Thrust Bearings

g. ***Lubrication***
Lubrication helps parts slide against each other, so it is used in bearings to reduce friction.

Let's try a small experiment. Rub your hands together very lightly and quickly. Your hands should feel warm. Where is the heat coming from? There is friction between your hands, and some of the energy you expend rubbing is turned into heat. If you put a lot of hand lotion or cream between your hands and rub, your hands slide more easily and should not get as warm. That is because the lotion acts as a lubricant.

Different lubricants work better with different materials. In the case of machines, one generally uses oil or grease to help the parts slide together easily. On a water slide, the water acts as a lubricant. If you bake cookies, a little oil or butter on the cookie sheet keeps the cookies from sticking.

Some appropriate lubricants for the fuel car bearings may be a light oil, light grease, or graphite powder (crushed pencil lead). Try various lubricants and see which ones work best in your car.

h. ***Wheel Alignment***
Another problem that wastes energy is poor wheel alignment. When the wheels on your vehicle are not lined up properly, the car may want to turn making some of the wheels must slide sideways. One way this might happen is sketched in Figure 10.

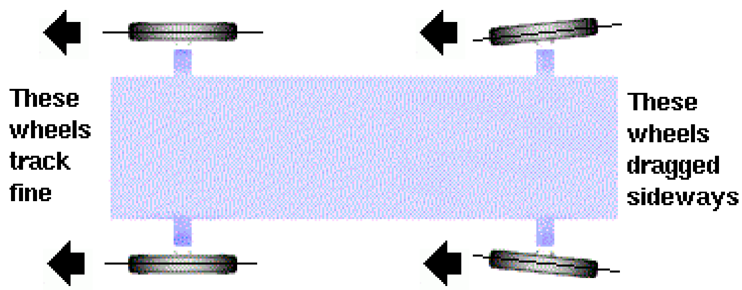


Figure 10: Wheel Alignment problem

When the driven wheels try to pull the car one way, but the rest of the car wants to roll the other way, the traction in the wheels (normally a good thing) wastes quite a bit of energy. Also, make sure that the axle goes through the center of the wheel. One suggestion is to use a compass, rather than tracing a circle out of a material. The compass will show you where the center of the circle is. Taking time to align the wheels carefully the first time will make a huge difference in how well your car runs. Testing your chassis with the wheels on it will be very important in identifying problems with the alignment.

4. **MATERIALS:**
For wheels: Look around for anything round, or things which can be cut into circular shapes...look at home, arts and crafts stores, and hardware stores. Hobby stores sell model wheels, but they are more expensive and are not designed for building a battery car. They may be too heavy. Some materials we found are useful are:

- Thin plywood
- Foam core
- Balsa wood
- Stiff plastic sheet
- Styrofoam
- Cardboard tubes
- Tin can
- Thread spool
- Plastic pipe
- Tape Spool
- Brass tube
- Wood dowels
- Toy/model wheels
- Old CD’s

For traction: Things that are rough or rubber-like usually add friction. Some materials we found are useful are:

- Rubber o-rings
- Rubber bands
- Rubber sheet
- Cloth tape
- Silicone or caulking

For axle: The axle must be stiff, narrow, and round. Some materials we found are useful are:

- Nails
- Brass rod
- Brass tubing
- Coat-hanger wire

For bearing: Bearings should be smooth and work well with the axle. Some materials we found are useful are:

- Screw eyes or bolts
- Brass tubing
- Hard material with hole drilled in it
- Brackets with screw holes pre-drilled
- Holes drilled in chassis
- Nylon bushings

5. **EXPERIMENTS & INVESTIGATIONS:**

Materials Needed:

- 1 large textbook
- 12 coins (similar size)

Procedure: (see Figure 11)

1. Put the heavy hardcover book flat on the table.
2. Rotate it slowly back and forth and get a feel for how hard it is to turn.
3. Put a stack of 3 coins on the table and balance the book on them.
4. Rotate it slowly back and forth again and note how hard it is to turn. (do not let the edges of the book touch the table)
5. Put a stack of 3 coins under each corner of the book.
6. Rotate it slowly back and forth again and note how hard it is to turn.
7. Repeat the last 2 steps each time moving the coin stacks closer to the center.
8. Is the flat book harder to turn because of more surface area in contact with the table?

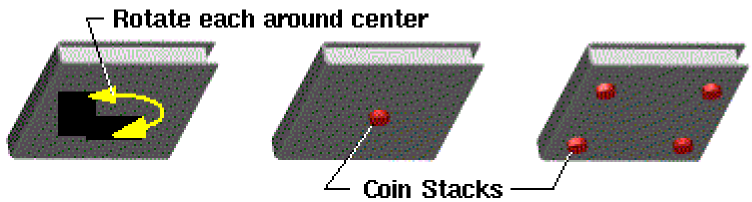


Figure 11: Friction investigation setup

Observations:
Where things are rubbing together makes a difference. Much like a lever, the farther from the center (pivot) a force is, the more effect it has. It is easier to stop spinning objects by grabbing the outside edge than a point near the middle. Therefore, a friction force far from the center slows a spinning object (such as a wheel) more quickly than the same force close to the center.

Friction Investigation

Materials Needed:

- Plank of wood
- Ruler
- Sheets of materials
- Small objects made of various materials
- Lubricants: oil, graphite, soap, etc.

Procedure: (see Figure 12)

1. Put the first sheet on the plank.
2. Place the first object on this wheel/plank setup
3. Tilt the plank until the object begins to slide on the sheet - note the height with the ruler.
4. Repeat this process with combinations of the sheets and objects you have.
5. Now repeat this process for all the objects and sheet combinations with different lubricants noting the heights in the chart.
6. Which combination of object and sheet had the least amount of friction? (moved at the lowest height)

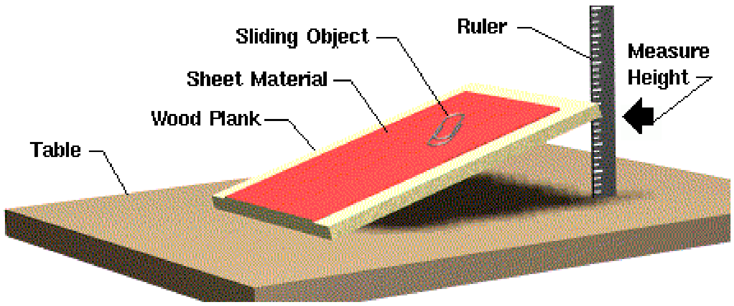


Figure 12: Friction investigation setup

To choose the best materials for axles and bearings find samples of the different materials you may want to use and test the friction between them.

Keep in mind that it can be difficult to un-lubricate something if it doesn't work, so test a scrap piece of material using this friction test before lubricating your car components if you are not sure.

SHEET Material and Description	OBJECT Material and Description	HEIGHT AT WHICH OBJECT SLID (by lubricant)			
		None	Soap	Oil	Graphite

Observations:

The lower the friction, the sooner the object will start to slide and the smaller the angle will be. One interesting feature of this investigation is that the weight of the object is not important. A steel paper clip will start sliding at the same angle as a heavy steel object. Picking two materials that "run" well together will mean that less power will be used to overcome the friction and more will go towards driving the car faster.

Rolling Resistance Investigation

Materials Needed:

- Ramp (plank)
- Several prototype cars
  - Without motors
- Various axle and bearing components
  - Approximately the same weight

Procedure: (see Figure 13)

1. Mark a start line on the plank.
2. Place the first car and let it roll down the ramp.
3. Mark the location it rolled to.
4. Repeat steps 2-3 3 times for each car or until the car repeatable rolls to the same place.
5. Repeat steps 2-4 for each car.
6. Did the cars travel in straight lines?
7. Which car went further?
8. Try improving your chassis/wheel car with different axles or bearings or lubricants and see how they alter the final distance the car travels.

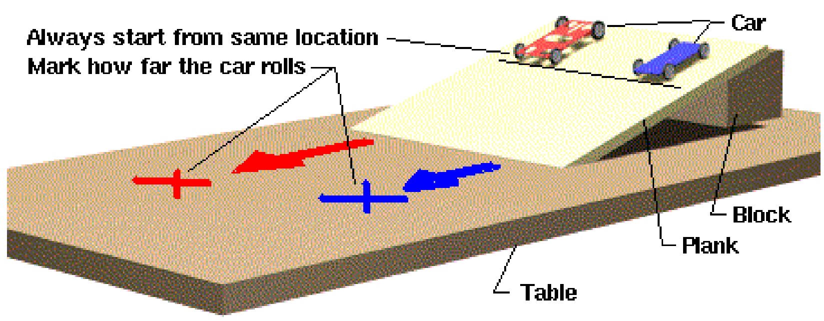


Figure 13: Rolling resistance investigation setup

Observations: Using this roll down test you can find the bearing and wheel configuration with the lowest rolling resistance (do not change the aerodynamics [shape] of the car during this test because that will also affect the results.) Finding the best combination is an important step in building a fast car.

5. Motors & Transmissions

1. **PURPOSE:**

A transmission transfers the power from the motor to the wheels. While doing so, it may make the wheels spin at a different speed than the motor.

2. **IDEAS:**

There are different ways to transfer power from the motor to the wheels. Some more popular techniques are shown in Figures 1 through 4 like direct drive, friction drive, belt or chain drive and gears. Some transmissions are easier to build than others, and not all are appropriate for a battery car.

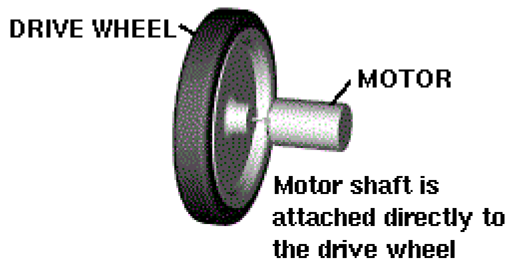


Figure 1: Direct Drive Transmission

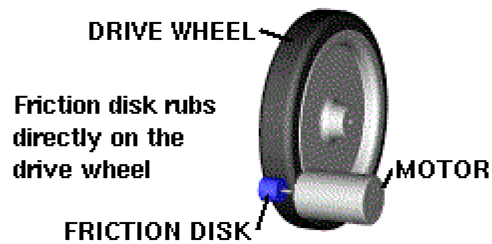


Figure 2: Friction Drive Transmission

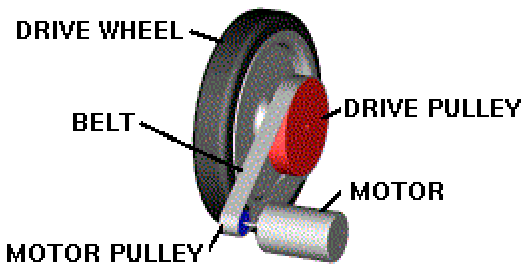


Figure 3: Belt Drive Transmission

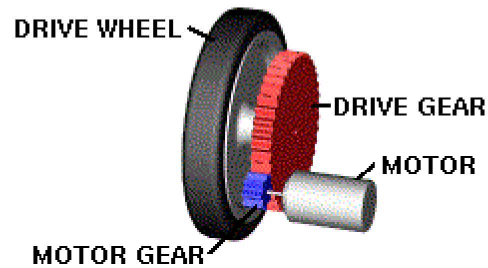


Figure 4: Gear Drive Transmission

3. **CONCEPTS:**

a. ***Speed vs. Force***

The simplest type of transmission is direct drive, which means the motor is connected directly to the axle of the driven wheel.

Direct drives are not common in vehicles; one of the few vehicles that use direct drive is a unicycle. Every time your feet make one revolution, the wheel makes one revolution.

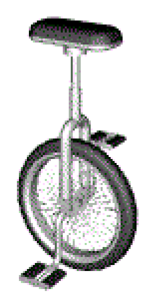


Figure 5: Unicycle

b. ***Speed***

Imagine two of your neighbors have a unicycle race. Bruce's unicycle has a regular wheel, and Karen's has a very large wheel. If they both pedal the same rate (number of revolutions per minute), which one of them will win?

In both cases, each revolution of the pedal means one revolution of the wheel. BUT, one revolution of Karen's wheel will roll twice as far as Bruce's. So Karen would win if they pedaled at the same rate. If Bruce wanted to win, he would have to pedal twice as fast as Karen

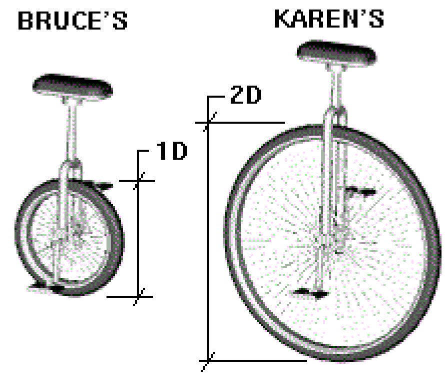


Figure 6: Different wheel sizes

Have you ever seen pictures of very old bicycles that have huge front wheels? These bicycles allowed the rider to go faster without pedaling like a maniac!

Figure 7: Old time bicycle

As mentioned before, most vehicles are not direct drive, so let's look at another type of vehicle: a 3-speed bicycle. A bicycle uses a chain drive. It allows you to move the pedal, and the chain transfers the energy from the pedals to the rear wheel (see Figure 8).

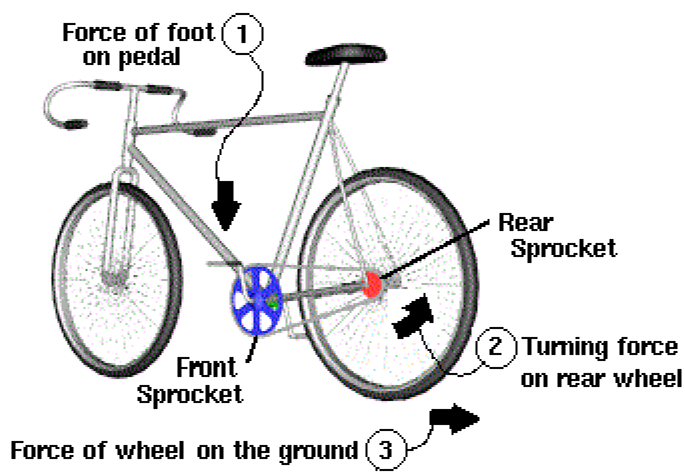


Figure 8: Forces on a Bicycle

The chain glides over different sized sprockets, depending on the speed of the rider. Which sprocket combination will make the rider go the fastest, given the same pedaling rate, or "cadence?" (Hint: how many times will the back sprocket [and therefore the back wheel] turn with each rotation of the front sprocket?)

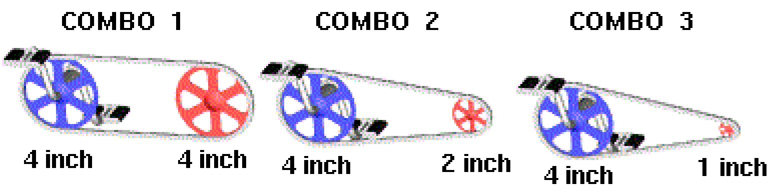


Figure 9: 3-Speed bicycle sprocket combinations

Each rotation of the front sprocket will make the back wheel rotate once in Combo 1, twice in Combo 2, and four times in Combo 3. So, combination 3 will go the fastest. (These sprocket combinations can also be called "gear ratios", because the new speed is calculated as the ratio of the driven (front) sprocket over the driven (back) sprocket.)

So how does this affect the way the biker would use the bicycle? Well, when the rider starts out, he/she uses first gear (Combo 1). As the rider pedals faster, the bike starts going faster. After a while, his/her legs are moving very fast, so he/she switches to second gear (Combo 2). Now his/her legs only go half as fast as a second ago, but the bike is still going fast. The rider can increase his/her cadence again and make the bike go even faster. Once his/her cadence is very high again, he/she can shift up to third gear (Combo 3).

If the rider is going 5 mph in first gear, how fast is he/she going in third gear with the same pedaling rate or cadence?

Well, the jump from first to second gear doubles the speed, and the step from second to third gear doubles it again. So, the rider is going four times as fast as in the first gear. He/She is going 20 mph, but his/her legs are moving at the same rate as at the very beginning!

The term "3-speed" bike is not entirely correct, because a biker can go more than just three different speeds. As we saw in the previous example, our bike rider was able to continuously speed up from 5 mph to 20 mph. But the name comes from the fact that given one cadence, the three gear ratios will give you three different speeds. Of course, your legs can pedal at many different rates, but "3-speed" bike sounds better than "3-gear-ratio" bike.

c. ***Force***

You may ask, then, why isn't it the best to go for the highest speed possible? Well, you can't get something for nothing! So what are you giving up when you gain speed? Let's investigate.

Imagine two bikers approaching a very steep hill. Jeff and Dave are both in third gear, because they are going very fast. Dave downshifts into second gear. But Jeff decides to stay in third gear, because he knows that third gear is for going fast, and he wants to go up this hill very fast.

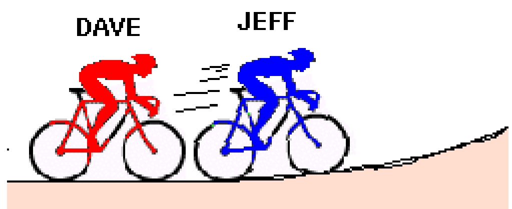


Figure 10: Dave downshifting at a hill

Dave is going half the speed now, because he just downshifted. Jeff smirks as he blows by Dave. But as Jeff hits the hill, he suddenly realizes that his legs can't go very fast anymore -- it becomes very hard to pedal! He gets slower and slower, and finally stops pedaling because it's too hard. Dave passes, slowly but surely, and makes it to the top of the hill while Jeff stops part way up.

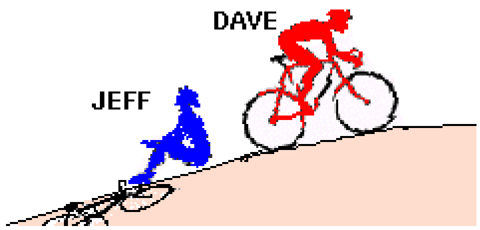


Figure 11: Jeff stops and Dave makes it

What happened? If only Jeff could have kept pedaling at the same rate, he would have beat Dave by a mile! Let's look at each pedal stroke. Each time Dave and Jeff pedal once, Dave's back wheel goes around once (let us say it travels 10 ft), but Jeff's back wheel goes around twice (20 ft).

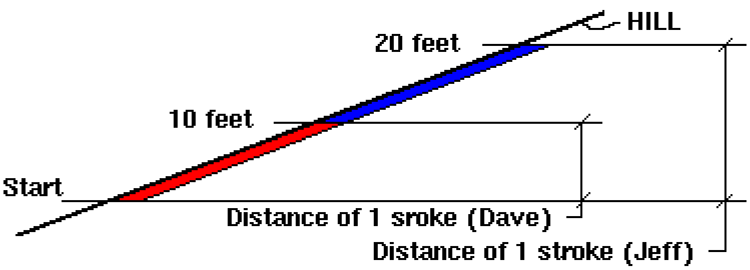


Figure 12: Distance Traveled per Stroke Comparison

Dave realizes that he only has to expend half the energy per pedal revolution than Jeff does, because Jeff goes twice as far each time. That is why Jeff started getting very tired, because his pedals were difficult to push. In other words, his pedals required more force than Dave's did.

So does Dave expend less energy going up the same hill?

Dave expends have the energy per pedal revolution, but this is only because he goes half the distance per revolution. Dave has to pedal twice as many times to get up the hill. So, the energy expended by both Dave and Jeff going up the entire hill would be the SAME in either case.

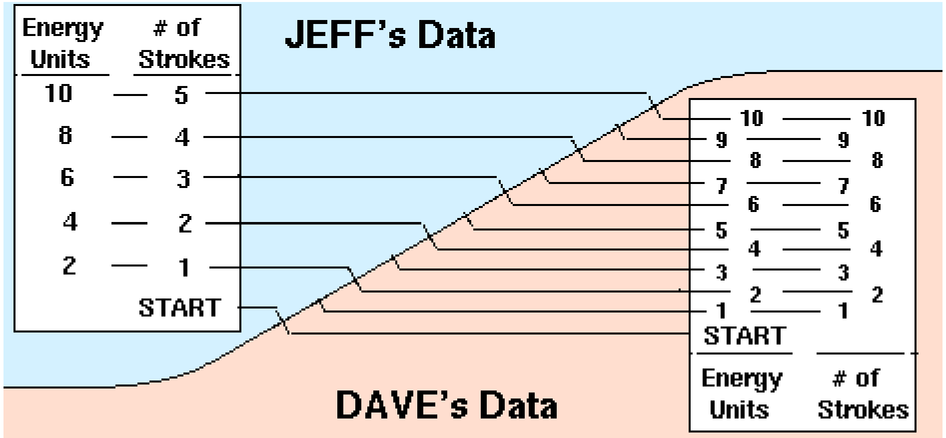


Figure 13: Energy units comparison

So, the bottom line is, when we gain a speed advantage, we are losing the force advantage. The pedals are more difficult to turn. You can gain either speed or force advantage, but not at the same time.

d. ***Selecting Proper Gear Ratios***

So, how can you choose the best gear ratio? Experimentation is probably the easiest way to find out. Try some of the Investigations below or build a test bed to try different combinations and note your findings.

The idea is that your motor, like your legs when you ride a bike, will like to go a certain speed. They also have a limit as to how much force they can exert. First you must find the speed at which the motor gives the most power (this is usually half the speed at which the motor will rotate if there is no load, or force, exerted on the motor shaft). Try to keep the motor turning at approximately that speed as you experiment with different gear ratios.

It helps if you build your car in such a way that you can change the gear ratios easily as you experiment. Remember, the ideal gear ratio may change some if you alter different characteristics of your car (size, weight, wheel size, etc.). Just remember, if your car is not going very fast it can either be that the wheel speed is too slow, or (like Jeff riding uphill) the force required to turn the wheel is too high. Try a different gear ratio!

3. **MATERIALS:**

The materials you choose vary greatly depending on the type of transmission you build. Remember that your car must roll under power from its battery with no pushing, so make good decisions.

Belt Drive: If you decide to build a belt drive you will need both pulleys and belt materials. Make sure your pulleys are pulled away from each other so that the belt is tight. One suggestion: one way to change the gear ratio on a pulley drive is to add or remove masking tape around a pulley which changes its diameter. Another thing to remember is that the pulleys must be securely attached to the motor axle and the other to the driven wheel. Some materials we found useful are:

a. Slide of inner tube
b. Rubber band
c. O-Ring
d. Spools
e. Drawer pulls
f. Videocassette reels
g. Reclaimed pulleys (Electronics parts)
h. Washers

Friction Drive: Make sure you have enough traction on the friction disk, or it will slip (See the materials section in Unit 4 – Wheels, Axles, & Bearings). Also, make sure the friction gears are pressed against each other snugly to ensure traction. Another thing to remember is that the gears must be securely attached to the motor axle and the other to the driven wheel. Some materials we found are useful are:

a. Parts out of model cars
b. Rubber bands
c. Circular wood or plastic cutouts
d. Spools

For Gears: Make sure the wheel axle is mounted securely in relationship to the motor axle to keep the teeth meshed on the gears. If they are not snug, the teeth may slip and you will lose power. Some materials we found are useful are:

a. Gears out of electronics
b. RC model car gears
c. RC model car gearboxes

In all cases, you will need wheel-like parts to put on the motor axle shaft and the wheel, and you can get ideas from Unit 4 – Wheels, Axles, & Bearings.

5. **EXPERIMENTS & INVESTIGATIONS:**

Pulley System Investigation)

Materials Needed:

- Board
- Hammer
- Nails
- Large & small spools
- Rubber band

Procedure: (see Figure 14)

1. Hammer two nails into a board far enough apart to lightly stretch the rubber band between them.
2. Place the large spool over one of the nails and one of the smaller ones over the other nail. They should turn freely.
3. Slip the rubber band around both spools so when one spool is turned the other moves.
4. Place a mark on the top edge of each spool and one on the board corresponding.
5. Beginning at the mark, turn the large spool through one complete turn.
6. How many times did the small spool turn?
7. In which direction did each spool turn?
8. Repeat the investigation for different sizes of spools and note the results.
9. What can you do to change the directions of the spools?
10. Does the length of the drive belt make a difference?

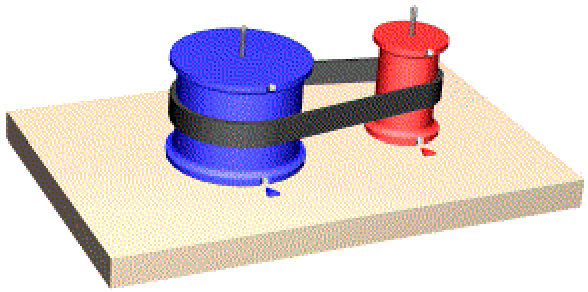


Figure 14: Pulley investigation setup

MOTOR Spool (you turn)			DRIVE Spool (pulley turns)			RATIOS	
Diameter (inches)	# of Revolutions	Direction (cw/ccw)	Diameter (inches)	# of Revolutions	Direction (cw/ccw)	$\frac{DIA_m}{DIA_d}$	$\frac{REV_m}{REV_d}$
2.0	1	cw	1.0	2	cw	2:1	1:2

Observations:

Drive belts are a form of pulley system that can be used to turn wheels. Observe the diameters of the spools and see if there is a correlation between the diameters and the number of terms ratios. Be sure and note in your data if you twist the rubber band (figure 8 type configuration) so you can make proper deductions about direction. Compare spool combinations at different distances apart also.

Gear System Investigation

Materials Needed:

- Plastic gears of different sizes (3)
- Mounting board
- Axles

Procedure: (see Figure 15)

1. Mark one tooth of each gear.
2. Count and record the number of teath on each gear.
3. Mount the largest and smallest gears of different sizes so their teeth mesh and their marks are aligned at the intersection point.
4. Turn the small gear to the right (CW) 1 revolution.
5. Record the direction and number of revolutions the large gear travels.
6. Return the gears to the start position and this time turn the large gear to the right (CW) 1 revolution.
7. Record the direction and number of revolutions the small gear travels.
8. Repeat steps 3 through 7 using the largest and middle sized gears.
9. Repeat steps 3 through 7 using the smallest and middle sized gears.
10. Try some variations in revolutions or other sizes.

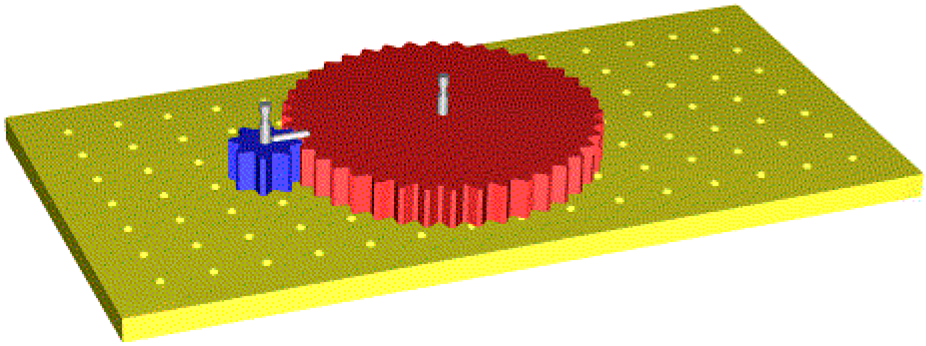


Figure 15: Gear investigation setup

MOTOR Gear (you turn)			DRIVE Gear (gear turns)			RATIOS	
# of Teeth	# of Revolutions	Direction (cw/ccw)	# of Teeth	# of Revolutions	Direction (cw/ccw)	$\frac{Teeth_m}{Teeth_d}$	$\frac{REV_m}{REV_d}$
10	1	cw	20	2	ccw	2:1	1:2

Observations:

The mechanical advantage in gears is determined by the ratio of the number of teeth on the gears. The pitch of a gear describes the number of teeth that can be put on a 1-inch diameter gear. Gears with different pitches will not fit together well, so the same pitch must be used throughout the transmission. Gears in 48 and 64 pitch are the ones most often used in slot cars. You can buy gears for the 1/24 scale slot cars at hobby shops.

Transmission Ratio Investigation

Materials Needed:

- Motor
- 3V power source (battery)
- 1 small pulley (motor axle)
- 3 larger pulleys (output axle see setup)
- Cardboard or foam board (chassis)
- Axle shaft (output axle)
- Rubber band or belt (pulley)
- Axle bearings (see setup)
- Hot glue or tape

Procedure: (see Figure 16)

1. Build the test transmission as shown in the setup figure (mount the motor to a piece of material so it can be moved to align with the different pulleys and stretch the belt drive).
2. Move the belt to different pulleys and see the results of the different ratios.
3. Which ratios give the highest speed?
4. Which ratios make the output axel easiest to stop with your finger?
5. Try different bearings on the output axle.
6. Does the bearing material affect the speed or ease of stopping the output axle?
7. Try adding or removing weight from the output shaft to see the effect on the system. Notice how flat rubber bands tend to crawl up the edges of a pulley - try a "crowned" pulley (convex profile) as shown in Figure 16. It is counter-intuitive, but does work, and is used often in machines.

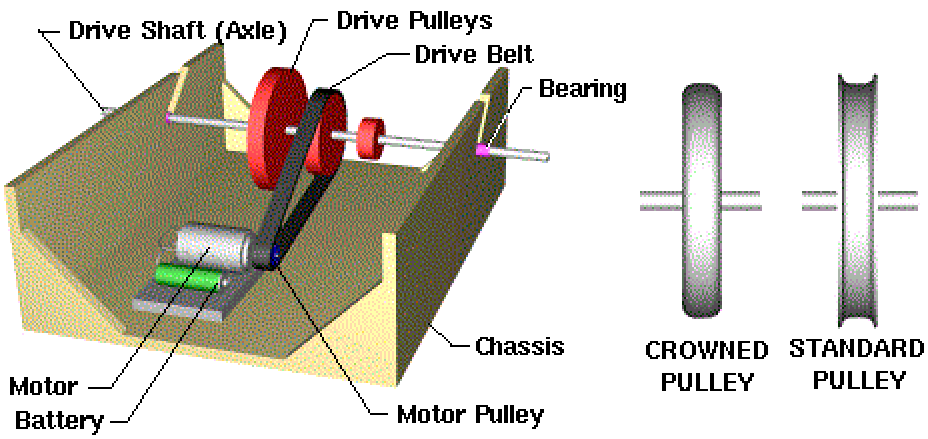


Figure 16: Transmission investigation setup

D_m Diameter of Motor Pulley		D_d Diameter of Drive Pulley	RATIO $\frac{D_m}{D_d}$	Rank each from 1 to n.... Highest Speed (Turns Fastest)	Highest Torque (Hardest to stop)
	Small				
	Medium				
	Large				

Observations:

Building a car without any knowledge of the best transmission ratio is risky because the car will not perform to its full potential (if it moves at all). This investigation uses a belt and pulley system, but the ratio of the pulley diameters applies to all the other types of transmissions as well (gears, friction drive). You can use this type of investigation in your final car as well to arrive at the best transmission for your design.

6. Gear and Wheel Calculations

1. **PURPOSE:**

To identify how to calculate gearing ratio requirements for your car rather than just by experimentation.

2. **IDEAS:**

The requirements for gearing ratios include the wheel size since it affects the speed vs. force conditions. The two transmission ratios and wheel size combinations shown below will produce cars with similar performance in terms of acceleration and top speed.

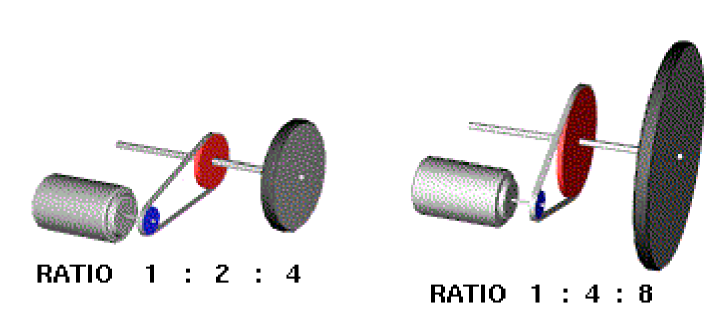


Figure 1: Transmission wheel combinations

The faster the axle rotates in the bearing the more friction and drag it will have. A large wheel will allow the axle to rotate more slowly (if the car is to go at the same speed), and will waste less power in the bearings.

In nature, an analogy for wheel size would be leg length. Just as a horse and hamster will travel different distances if each takes one step per second, cars with large and small wheels will travel different distances with each wheel rotation.

3. **CONCEPTS:**

a. ***Known Values***

Motor Speed	w_m	**8300** rpm	(revolutions per minute) under load 0.278 in-oz torque at that speed
Vehicle Speed	V	**300** cm/sec	Fast cars cover the track in 6.5 seconds. Track distance = 10m (32.8 ft), V=10m/6.5sec -or- 1.53 m/sec

b. ***Gear Ratio Known***

If we have a set of pulleys or a couple of mating gears then we already have the gear ratio. Now we just need to find out what size drive wheel(s) we need to be competitive.

Figure 2 shows how a pulley or gear system might look.

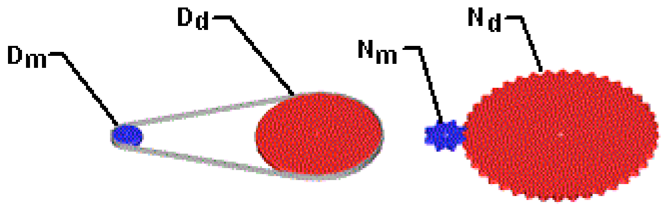


Figure 2: Pulley and Gear Systems

The variable **D** is the diameter of the pulley, and variable **N** is the number of teeth on the gear.

The subscript **d** refers to the gear or pulley attached to the drive axle and the subscript **m** refers to gear or pulley attached to the motor. For sample purposes we have supplied values for these - use your own values to do the calculations on your own transmission.

The variables for a Pulley System

D_m = **1.25** cm D_d = **0.25** cm *The*

variables for a Gear System N_m =

40 teeth N_d = **8** teeth

The variables for a YOUR System

[__]$_m$ = **[__________]** **[__]$_d$** = **[___]**

Step 1: Determine the gear ratio.

For a Pulley System the gear ratio is

$R = D_m / D_d$ or **R** =**1.25** cm / **0.25** cm or **R** =**5**

For a Gear System the gear ratio is

$R = N_m / N_d$ or **R** =**40** / **8** or **R** =**5**

For YOUR System the gear ratio is

R = **[__]$_m$** / **[__]$_d$** or **R** =**[__]** / **[__]** or **R** =**[__]**

Step 2: Find out the speed of the wheel in rpm.

For a Pulley or Gear System wheel speed is

$w_d = w_m / R$ or w_d = **8300** rpm / **5** or w_d = **1660** rpm

For YOUR System wheel speed is

$w_d = w_m / R$ or w_d = **[__]** rpm / **[__]** or w_d = **[__]** rpm

Step 3: Find out wheel speed in revolutions per second.

For a Pulley or Gear System wheel speed in rps is

$w_d = w_d$ / **60** spm or w_d = **1660** rpm / **60** spm or w_d = **27.6** rps

For YOUR System wheel speed in rps is

$w_d = w_d$ / **60** spm or w_d = **[_]** rpm / **60** spm or w_d = **[_]** rpm

Step 4: Calculate the wheel circumference.

To determine the wheel diameter we first need to know the circumference of the wheel (the distance the car will travel each time the wheel turns one full revolution).

For a Pulley or Gear System the circumference is

$C = V / w_d$ or C = **300** cmps / **27.6** rps or C = **11** cm

For YOUR System the circumference is

$C = V / w_d$ or C = **[__]** cmps / **[__]** rps or C = **[__]** cm

Step 5: Determine the wheel diameter.

Now we can find out what diameter wheel, D_w we need. The wheel diameter is determined from the circumference.

For a Pulley or Gear System the diameter is

$D_w = C$ / **pi** or D_w = **11** cm / **3.14** or D_w = **3.5** cm (1.4 in)

For YOUR System the diameter is

$D_w = C$ / **pi** or D_w = **[__]** cm / **3.14** or D_w = **[___]** cm

Step 6: Check calculations.

Now check to make sure the diameter of your wheel is bigger than the diameter of the drive gear. If it is, you're up and running. If it is not, you need to choose smaller pulleys or gears.

c. ***Wheel Size Known***

If we already have a wheel size we want to use we must find a suitable gear ratio to drive it. For sample purposes we have supplied values for these - use your own values to do the calculations on your own transmission.

The variables for a Wheel

D_w = **8** cm (3.1 in)

The variables for a YOUR Wheel

D_w = **[___]**

Step 1: Calculate the wheel circumference.

For a Pulley or Gear System wheel circumference is

$C = D_w$ * **pi** or C = **8** cm * **3.14** or C = **25** cm

For YOUR System wheel circumference is

C = D_w * **pi** or **C** = [__] cm * **3.14** or **C** = [__] cm

Step 2: Find the wheel speed in revolutions per second.

For a Pulley or Gear System wheel speed in rps is

w_d = **V** / **C** or w_d = **300** cmps / **25** cm or w_d = **12** rps

For YOUR System wheel speed in rps is

w_d = **V** / **C** or w_d = [__] cmps / [__] cm or w_d = [___] rps

Step 3: Find the wheel speed in revolutions per minute.

For a Pulley or Gear System wheel speed in rpm is

w_d = **60** spm * w_d or w_d = **60** spm * **12** rpsor w_d = **720** rpm

For YOUR System wheel speed in rpm is

w_d = **60** spm * w_d or w_d = **60** spm * [__] rps or w_d = [______] rpm

Step 4: Determine the gear ratio.

For a Pulley or Gear System the ratio is

R = w_m / w_d or **R** = **8300** rpm / **720** rpm or **R** = **11.5**

For YOUR System the ratio is

R = w_m / w_d or **R** = [_________] rpm / [___] rpm or **R** = [__]

Step 5: Design the transmission.

Since the drive pulley or gear can be no larger than the drive wheel, we need to select a pulley or gear accordingly.

For a Pulley System we might select a drive pulley of 6 cm in diameter.

D_m = D_d / **R** or D_m = **6** cm / **11.5** or D_m = **.52** cm

For a Gear System we might select a drive gear of 69 teeth.

D_m = D_d / **R** or D_m = **69** teeth / **11.5** or D_m = **6** teeth

For YOUR System select a drive pulley or gear that is appropriate

D_m = D_d / **R** or D_m = [__] / [__] or D_m = [___]

Notes

In these calculations friction and wind drag were not considered. In a battery car, friction and drag will affect performance. To compensate we need to make the wheel diameter smaller, or the gear ratio bigger if we are going to get the best performance. This fine tuning of the car performance will need to come from experience gained by testing the car, but these calculations will give you an idea of where to start.

Notice that we came up with two different combinations of gearing and wheel size. There is an infinite number of combinations that will work well. What you come up with for your car depends on what you have available to you for constructing your car.

4. **MATERIALS:**

See Units 4 and 5 for information on materials for Wheels, Axles, Wheels, & Bearings and Motors & Transmissions.

5. **EXPERIMENTS & INVESTIGATIONS:**

Effect of Wheel Size Investigation

Materials Needed:

- Prototype car
  - Chassis
  - Wheel
  - Motor
  - Temporary power source (3V battery)
- Lightweight foam tape

Procedure: (see Figure 3)

1. Experiment with the varying of wheel diameter by building up the diameter of the drive wheel(s) on your prototype car using various materials.
2. How much larger would the wheels need to be to make the car's top speed twice as fast?
3. Three times as fast?
4. How can large wheels hurt the performance of your car?
5. How does the size of the wheels affect acceleration?

Try using materials like weather-stripping foam tape to increase the diameter of the wheels.

Figure 3: Investigation setup – add to size of the drive wheels

Observations:

Wheel size is as important a factor in the car's design as the transmission ratio; in fact, they are closely related. Try to calculate what distance your car travels per one revolution of the motor. The transmission ratio will tell you how many revolutions the wheel axles will turn per motor revolution, and the size of the wheels will tell what linear distance the car will travel per wheel revolution.

7. Motors, Electricity, & Solar Panels

a. PURPOSE:

The purpose of the solar panel is to capture energy from the sun and to turn this energy into electrical energy used to convert water into hydrogen and oxygen through electrolysis. The fuel cell panel then uses the hydrogen to produce energy to then use the energy to power the electric motor to drive the wheels of the fuel cell car.

b. IDEAS:

The basic configuration of solar panel and motor. **(battery pack will be substituted for solar panels)**

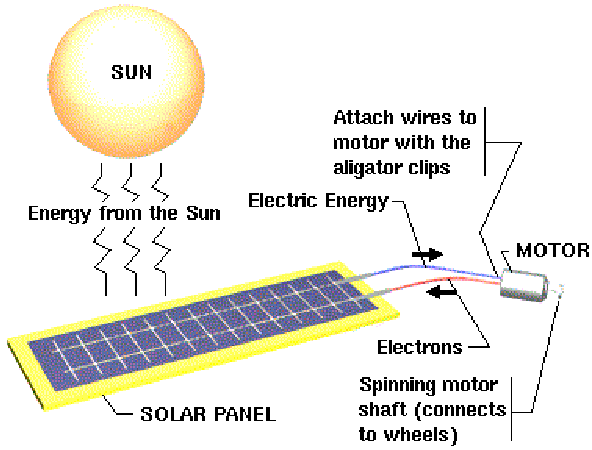


Figure 1: Solar Panel motor configuration

3. **CONCEPTS:**

a. ***How a Solar Panel works***

When you look at the diagram above, you might ask, "How does the solar panel turn the sun's energy into electric energy?" The solar panel is made of a sandwich of two materials called *semiconductors*. Each material is made of millions of atoms. As you might already know, atoms have a positively charged *nucleus*, and negatively charged *electrons* which spin around the nucleus. When these two materials are put together in a sandwich, an interesting thing happens: electrons become pulled from the bottom half. But there's a problem. The electrons are all attached to atoms, and the atoms won't let go very easily. This is where the sun's energy helps out. If we shine sunlight on these materials, the sunlight has enough energy to knock the electrons off of the atoms. The electrons will then be free to be pulled to the top of the sandwich.

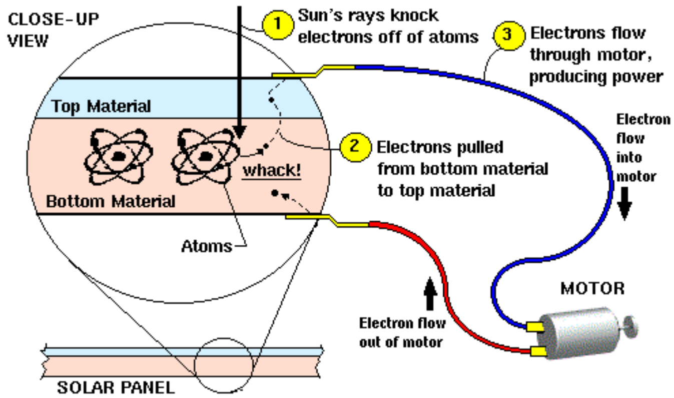


Figure 2: How a solar panel works

Now if we connect wires to a motor, electrons will flow through the wire into the motor (making it spin) and back through another wire to the solar panel where they can fill the "holes" left in the atoms who lost their electrons.

b. ***Power***

How does such a solar panel create power? To understand power more clearly, let's look at a mechanical example to illustrate the main ideas. For example, imagine a water wheel, like the one in Figure 3.

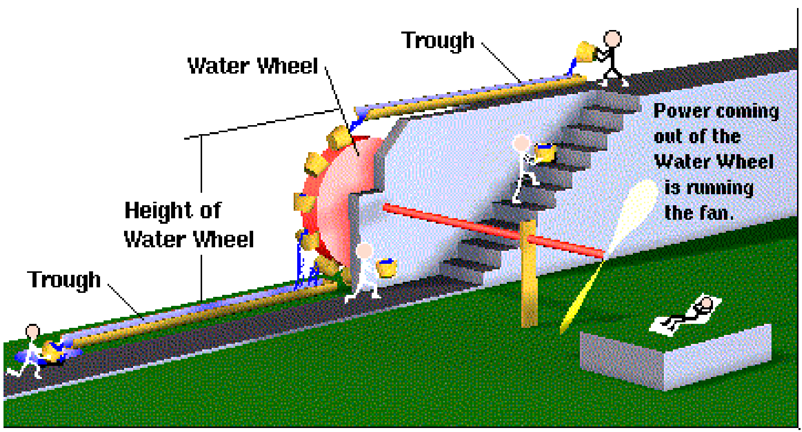


Figure 3: Mechanical example of power system

This does not look very much like a solar panel and motor, but we will see that in many ways they are actually quite alike. In this example, the people have to climb stairs to carry buckets of water up a hill, and then pour the water into a trough. The water flows down over a "water-wheel", which has buckets attached to it that catch the water. The weight of the water in the buckets is what makes the wheel spin. Now, we can use the power of the spinning wheel to run a machine, like the big fan in the picture. For the water-wheel, the *power* coming out depends on two things:

1. How *high* the water falls.
2. How *much* water (how many buckets) is poured over the wheel.

In fact, the power you get is:

Power = Height x Amount of water

The larger the height of the wheel, the more power we get, and the more buckets of water we pour over the wheel, the more power we get.

No let's think about the solar panel and the motor. Imagine that the electrons are buckets of water, the wires are like the troughs, and the electric motor is the water wheel. In the solar panel, then, the sun's energy is used to carry the electrons up on electric "hill" inside the solar panel, then they are "poured" down through the motor. So, if we drew the picture again for the solar panel, it would look like this:

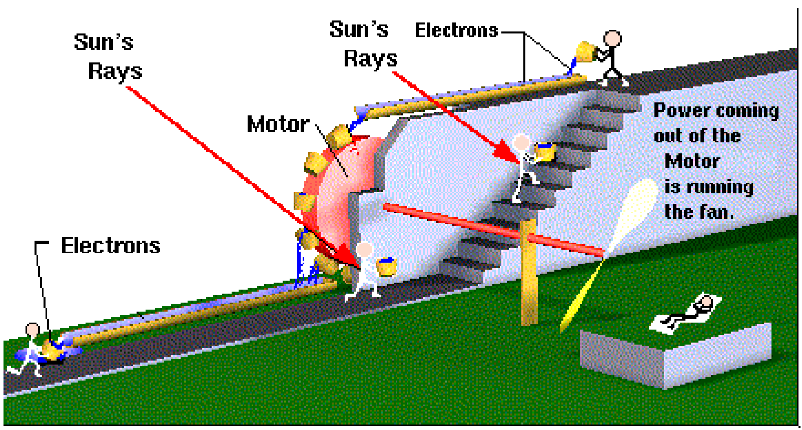


Figure 4: Solar version of Mechanical model

In the solar panel, a very similar equation for power is true as for the water wheel. But instead of height, we have what is called *voltage*, and instead of buckets of water, we have *electric current* (or the number of electrons flowing through the motor).

The *power* coming out of the solar panel is the product of the *voltage* and *the current* (the number of electrons flowing):

Power = Voltage x Current

c. ***Maximizing Power***

We can we build a car powered by solar energy by attaching a solar panel to an electric motor. How can we build a solar car so it gives us the most power from the solar panel?

One way is to try to get the solar panel to produce more current. To produce current, more electrons need to be forced to move inside the panel. If more sunlight hits the solar panel, more electrons are knocked away from atoms in the solar panel and more current is then produced!

How can we do this? One way is to tilt the solar panel towards the sun. The more of the sun's rays hit the panel, the more current will flow and the more power will be produced. Look at the two cars in Figure 5:

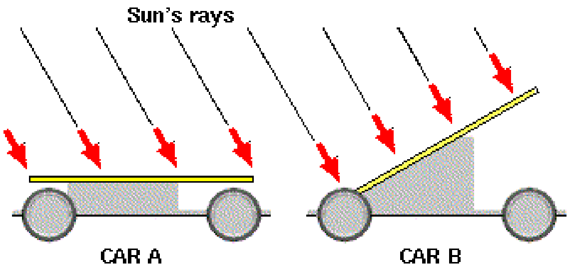


Figure 5: Orientation of the Solar Panel

Which one would have more power? In this case, car B would, because it has more sunlight hitting it than does on car A.

Of course, the best way to tell if this will affect your car is to try it with the solar panel mounted at different angles -- experiments are the best way to find out.

Another idea that you might want to experiment with is using a reflector to capture more sunlight with the solar panel.

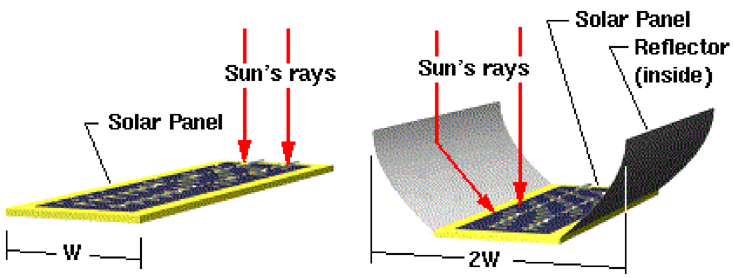


Figure 6: Reflectors on a solar panel

On the right, a reflector that is twice as wide as the solar panel could be made to direct twice as much sunlight to it. This would double the current coming out of the solar panel and double its power!

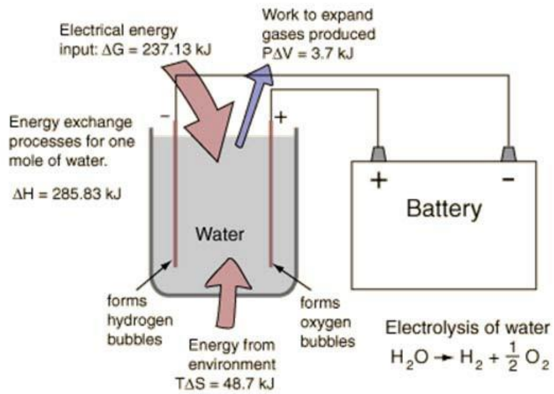
The disadvantage is that the car would be heavier with a reflector, and a heavier car will be harder to move. Also the reflectors might add air drag or get caught in side winds causing the car to tip over. But, as usual, the only way to find out is to build one and see!

d. Can we use the solar panel to produce hydrogen?

Yes, through the process of electrolysis, we can use the electrical energy produced from a solar panel to change water into its two constituent components, hydrogen and oxygen.

Electrolysis of Water

By providing energy from an electrical source, provided by a battery or solar panel, water (H_2O) can be dissociated into the diatomic molecules of hydrogen (H_2) and oxygen (O_2).

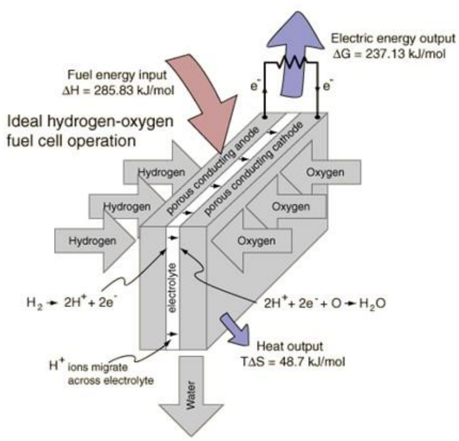


The electrolysis of one mole of water produces a mole of hydrogen gas and a half mole of oxygen gas in their normal diatomic forms. A detailed analysis of the process makes use of the thermodynamic potentials and the first law of thermodynamics.

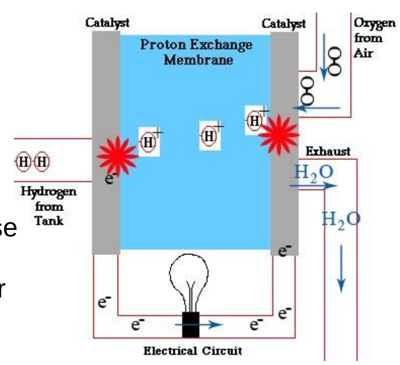
The process must provide the energy for the dissociation (breakup) plus the energy to expand the produced gases. This change in internal energy must be accompanied by the expansion of the gases produced, so the change in enthalpy represents the necessary energy to accomplish the electrolysis.

Hydrogen Fuel Cell

Hydrogen and oxygen can be combined in a fuel cell to produce electrical energy. A fuel cell uses a chemical reaction to provide an external voltage, as does a battery, but differs from a battery in that the fuel is continually supplied in the form of hydrogen and oxygen gas. It can produce electrical energy at a higher efficiency than just burning the hydrogen to produce heat to drive a generator because it is not subject to the thermal bottleneck from the second law of thermodynamics. Its only product is water, so it is pollution-free.



All these features have led to great excitement about its potential, but we are still in the process of developing that potential as a pollution-free, efficient energy.



Combining a mole of hydrogen gas and a half mole of oxygen gas from their normal diatomic forms produces a mole of water.

Energy is provided by the combining of the atoms and from the decrease of the volume of the gases. For this ideal case, the fuel energy is converted to electrical energy at an efficiency of 83%! This is far greater than the ideal efficiency of a generating facility which burned the hydrogen and used the heat to power a generator! Although real fuel cells do not approach that ideal efficiency, they are still much more efficient than any electric power plant which burns a fuel.

Comparison of electrolysis and the fuel cell process.

In comparing the fuel cell process to its reverse reaction, electrolysis of water, it is useful treat the enthalpy change as the overall energy change. The Gibbs free energy is that which you actually have to supply if you want to drive a reaction, or the amount that you can actually get out if the reaction is working for you. So in the electrolysis/fuel cell pair, you have to put in 237 kJ of energy to drive electrolysis and the heat from the environment will contribute 48.7 kJ to help you. Going the other way in the fuel cell, you can get out the 237 kJ as electric energy, but have to dump 48.7 kJ to the environment.

The energy produced by combining the hydrogen and oxygen in the fuel cell is the energy supplied to the electric motor to drive the wheels of the fuel cell car.

4. **MATERIALS:**

The Solar Panel and Motor will be supplied to you with wires for connection. You may add more wiring if you need it or even add an on-off switch if you like.

5. **EXPERIMENTS & INVESTIGATIONS:**

Sun's Angle Investigation

Materials Needed:

- Solar Panel
- Motor
- Straw
- Protractor
- Propeller
- Sunshine

Procedure: (see Figure 3)

Do this at 3 different times of day (i.e., 8am, 11am, 2pm).

1. Attach the propeller to the motor shaft.
2. Connect the motor to the solar cell.
3. Go outside and hold the solar cell level.
4. Count how many times per minute the propeller turns.
5. Hold straw so it is parallel to the sun's rays and casts no shadow (other than a ring).
6. Measure the angle of the straw to the level plane (solar cell) using the protractor.
7. Note the angle, propeller turns and weather conditions at each trial.
8. Repeat these steps on 3 separate days.

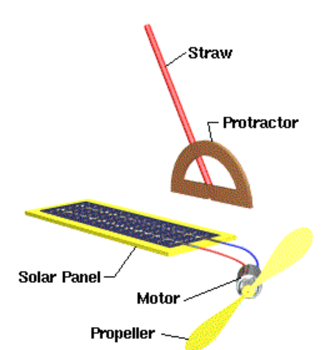


Figure 7: Sun's angle investigation setup

Calculate the average turns over the 3 days for each of the times the observations were taken.

Record the Number of Turns observed and the Sun's Angle at different times of day:							
Date	8am		11am		2pm		Weather Conditions
	Turns	Angle	Turns	Angle	Turns	Angle	
Average							

Observations:

The angle of the sun is different at different times of the day and affects the power for electrolysis. Weather conditions also affect the power available. Make deductions based on your results, when the race will be held and your strategy in the design of your car.

8. Body Shell & Aerodynamics

1. **PURPOSE:**

The body or shell of a real car has several purposes. It protects the passengers from wind and rain, it provides added safety in case of a crash, and it improves how the car looks. But it also changes how the car performs because a well designed shell can reduce the force of air on the car as it moves.

2. **IDEAS:**

Some ideas for shells are given below.

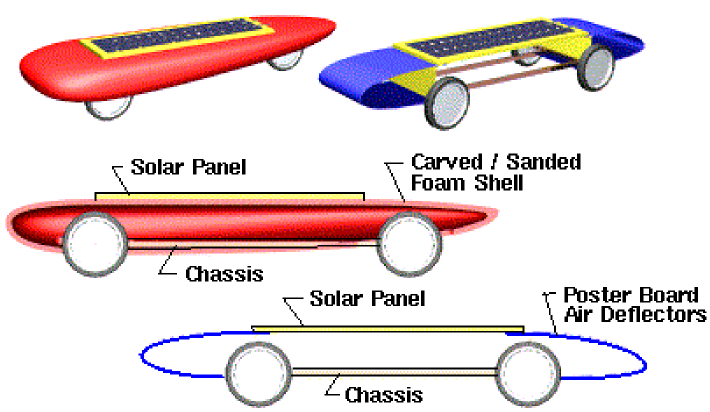


Figure 1: Shell or body concepts

3. **CONCEPTS:**

a. ***Aerodynamics***

Aerodynamics: a branch of dynamics that deals with the motion of air and other gaseous fluids and the forces acting on bodies in motion relative to such fluids. Air is a gas and produces a resistance force to objects that move through it.

To see how much force air can have, you can try some simple experiments. While driving in a car, carefully try holding your hand flat, and sticking it out of the window. Feel how much force the air has on your hand. What happens to the force when you tilt your hand?

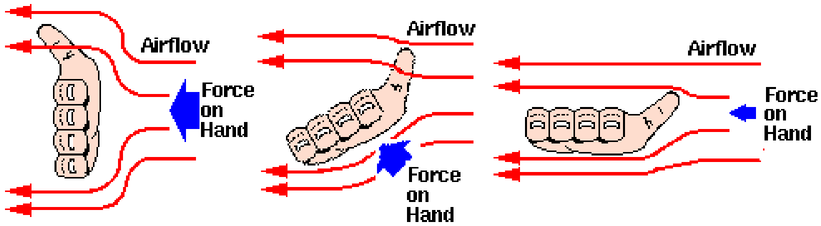


Figure 2: Force of air on your hand

b. ***Frontal Area***

When looking at the front of an object that is moving through the air, you can see the "frontal area" that the air must move around. The smaller the frontal area the less air has to be moved around the object so the less force is required to move through the air.

To illustrate this concept try riding a bike down a hill, compare how fast you can go while sitting upright, or by leaning forward. If you crouch down, the air can go over you instead of hitting you in the chest, so you should be able to go faster. In other words, the force of the air on your body when you crouch down is less, so you are more aerodynamic.

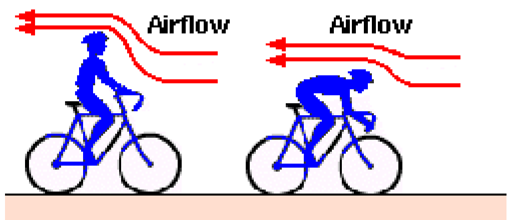


Figure 3: Bicyclist and frontal area

c. ***Shaping***

The shape of the object affects the way the air goes around it. The air wants to stay in a nice smooth flow around the object, however, fast changes in shape create "holes" in the air that disrupt this flow and increase the "drag" or resistance of the air on the objects movement.

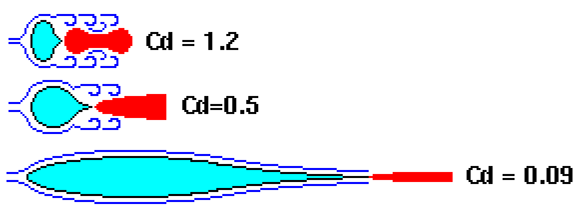


Figure 4: Shapes and airflow

Look at things that move through the air, and notice how they are shaped. For example the two cars shown below, notice how the air flow around them is affected by the shape.

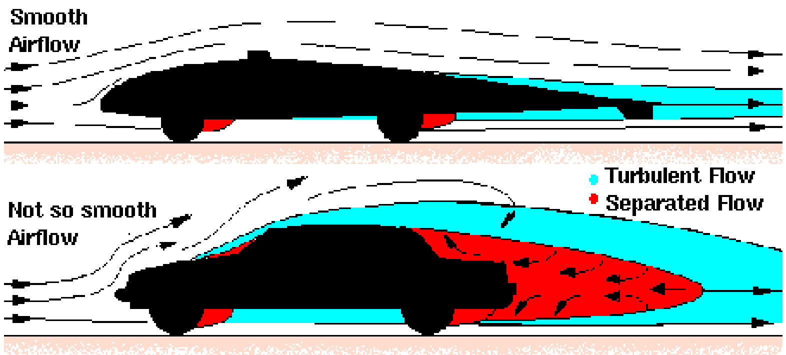


Figure 5: Smooth verses disrupted flow

Fast cars are shaped so that, when moving quickly, they can move more easily through the air. As another example, you may have seen tractor-trailer trucks with big air deflectors on them. The reason for this deflector is to make the truck more aerodynamic, so the truck's engine doesn't have to work as hard and the truck driver saves money on gas.

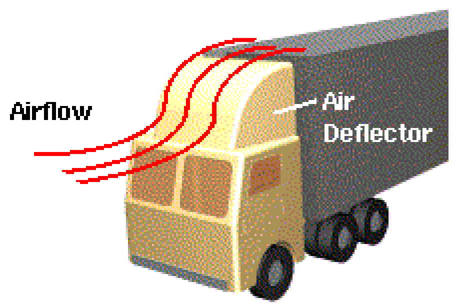


Figure 6: Semi truck and deflector

In some situations, the force of air helps you instead of hurting you. For example, what if you want to slow down very fast? How about using a parachute? Or if you want to create more pressure on the drive wheels without adding weight - you could add a wing that creates a down force on the car. Now the force of the air is helping you.

4. **MATERIALS:**

So how do you reduce the force of air on your solar car? One way might be to add a body or shell to it that deflects the air around the car. Some possible materials you might want to use are:

- Poster board
- Cardboard
- Foam core
- Stiff insulation foam (Foamula)
- Mylar or plastic sheet
- Paper

Insulation foam can be carved to a shape, made smooth with sandpaper, and even painted to look nice. (Warning: some paints, likes spray paint, will "melt" foam, so always try your paint on a piece of scrap foam that you don't need before using it on the real thing.)

Radio control modeling stores also carry an acrylic that can be heated and shaped over a mold of your own construction.

5. **EXPERIMENTS & INVESTIGATIONS:**

Aerodynamic Shape Investigation

Materials Needed:

- Soda can (empty)
- Sheet of paper
- Tape
- 2 - 1/2" diameter wooden dowels (3' long)

Procedure: (see Figure 7)

1. Set up dowels as shown.
2. Place the can alone on the dowels.
3. Blow on the can and observe its movements and the strength of the blow.
4. Make a cone out of the paper and tape it to the front of the can.
5. Now place the can with the cone facing the side to blow from.
6. Blow on the can and observe its movements and the strength of the blow.
7. What kind of resistance forces would the can feel if it were a moving vehicle?
8. How does the cone end can compare with the flat end can?

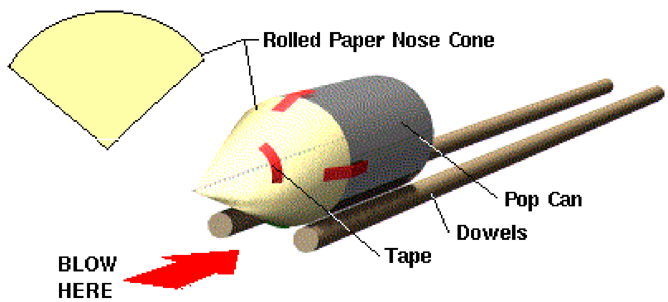


Figure 7: Aerodynamic shape investigation setup

Observations:
In this case the frontal area (area projected to the front or direction of the air movement) did not change, but the shape affected the amount of force applied to the object. How can you apply these principles to your car to make it faster?

Aerodynamic Shape Investigation

Materials Needed:

- Ramp (plank of wood)
- Simple car chassis (derby car)
- Different shapes to attach to chassis
- Pieces of Foam core

Procedure: (see Figure 8)

1. Set up a ramp as shown.
2. Identify a starting line.
3. Release the simple car chassis until it repeatably rolls to the same place.
4. Mark the location.
5. Repeat with different frontal area (sheets of foam core of different sizes and orientation), keeping the weight of the car consistant. Try a very large frontal area.
6. Mark the locations they roll to.
7. Which tests went the farthest? Smallest frontal area or largest?
8. Repeat these steps using different steamlined shapes as you did with the nose cone on the soda can. Be careful to keep the other variables constant.
9. Why is it invalid to use different test cars (chassis)? What other physical properties can affect the amount of distance traveled?

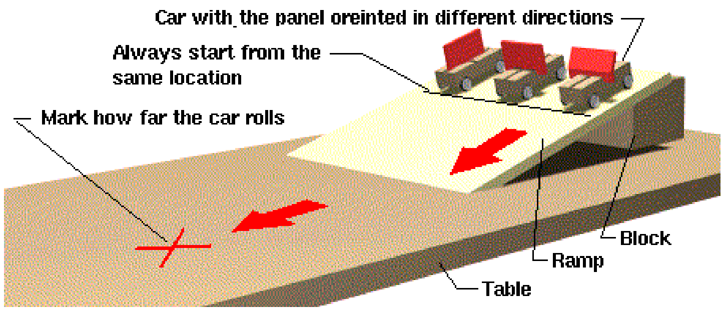


Figure 8: Aerodynamic shape investigation setup

Observations:

Roll-down tests are used by some automobile manufacturers, race car builders, and car testing organizations (among others) to test the aerodynamic drag of a car. The idea is to roll a car (with the engine turned off and out of gear) down a hill and see how far it rolls. A car with more drag (for example, a car with a parachute behind it) will roll to a stop faster (or in a shorter distance) than a streamlined, low drag car.

In this case the frontal area did change. Make observations on how the frontal area and shape can affect the drag or resistance the air has on your vehicle. How can you apply these principles to your car to make it faster?

9. Select overall design & prepare presentation

1. **PURPOSE:**

A design review is an opportunity for any organized team of developers to gather all the information together and review it - establishing a more refined approach to the problem. At this point you have learned something, through study and investigation that will help you narrow the options you have in producing your car. A design review is where you take establish a design (in the form of a drawing and maybe with some of the "prototypes" you have already made) and present it along with the reasoning behind the decisions you have made to others. The presentation is then followed by a question / answer and comments period where the audience gives you feed back. Your team can then take this input and finalize the design you are going to build.

2. **IDEAS**:

Some ideas for this presentation.

- A final sketch or drawing of the car (overhead)
- Examples in the form of sketches or prototypes
- Samples of the materials you plan on using
- Samples of processes you plan on using
- Experiences in trying things that you learned from

3. **CONCEPTS:**

a. ***Presentation***

Hold a team meeting to review all of the information you have learned about chassis, wheels & bearings, transmissions, solar panels, motors and bodies. Decide as a group what your final approach will be in each of these areas (for example a pulley & belt transmission) and record them on paper with small sketches of what you want to build.

You can also use prototype projects you have already completed. Also record the reasons why you are making these choices. You might also record any statements on strategy that are affecting your design decisions such as "we expect a cloudy day - so we will build a transmission that will make the car move with very little sunlight."

If you plan on doing anything special with a material in producing your car include statements on how you plan on doing the work.

The presentation for you Solar Sprint car should be about 5 minutes long. Make assignments in your group to produce a sketch (with critical dimensions) or drawing of your final concept. Have a transparency of the picture produced.

Identify one of your team members to make the presentation and another to act as a recorder of the comments that you receive. These notes can be very helpful in making final decisions after the design review with your peers.

When making the presentation, remember that you are not only sharing your ideas but trying to sell your audience on them. Make the presentation fun and exciting. Showcase your ideas and see what kind of reactions you get.

Remember that the comments and questions are not personal. It is just others trying to understand what you are saying or giving you ideas they have. In the end, you will, as a team, make the final decisions on what you are going to build. The Design Review is a tool to try and help you produce a better vehicle.

b. ***The audience***

When a team is presenting their design, you need to be attentive. Do not interrupt the presentation and only express an idea or ask a question when called upon. The members of the audience need to be supportive of ideas they think are good, but also ask questions to clarify what you do not understand. You should freely express concerns about ideas that might have problems such as something you learned in an investigation that had different results. You are responding to the presentation to help the presenting team produce a better more competitive car.

You also need to listen intently because you can learn things from other presentations that might help your team do better. Take notes when you hear something that impresses you or is a good idea.

Remember, the better all the cars are the better the race and the more fun for all - you, your team-mates, the other racers and the audience that comes to see the results of all your hard work.

c. ***Considerations for a Battery-powered Car***

A battery-powered car, whether full sized or a smaller model, must perform with very little energy available from the battery. Since the energy is limited, the designer must do everything possible to make the car efficient so that the maximum amount of energy is used to make the car go.

In a battery car, we have to consider many things. With the solar panel area limited, we have to have the most efficient solar cells possible. The electrical load on the solar panel has to maximize the power under any condition of sunlight. The motor for driving the wheels had to be very efficient, too. In the Alternative Fuels Challenge, everyone must use the same solar panel and motor so these are not a matter of design for this application. What are the design points which have the greatest impact? They are aerodynamic drag, rolling resistance, drive train efficiency and weight.

Aerodynamic Drag is very non-linear with speed. At very slow speeds, below 10mph, it doesn't have too much effect, but as the speed increases to more than 30mph, aero drag gets important. The magnitude of drag depends on the frontal area of the car; (i.e. maximum cross section looking at the car from the front, multiplied by the coefficient of aero drag, which depends on the car's shape, multiplied again by the velocity squared). It is this velocity squared term that makes the drag increase quickly with velocity or speed.

So the designer should make the frontal area of the car as small as possible and make the body as streamlined as he or she can. A poorly designed shape might have a coefficient of 0.5 (drag), and a very good shape might be as low as .02 (drag). So you can see that the drag could range over four to one!

Make a smooth shape as well as you can. Use the wheels with disc structure, not spokes. If spokes are used, they should be covered on both sides. Be sure the underbody is smooth, too, not open like a regular car. Make openings for the wheels (if the body covers the wheels) as small as possible. If the wheels are not enclosed in the body, consider wheel pants.

Rolling Resistance is another energy waster. It is the energy lost in the wheel bearings and in the tire deformation. The tires on the car are probably solid rubber so tire pressure is not a factor, but the rubber should not be very soft and the tires should be smooth (no tread) and very narrow. The bearings should be given careful attention. The axles should be straight and the bearings (if they are sleeved bearings) should be made from low friction materials like Teflon, Nylong or Oilite (bronze). The lubrication should be very light - no grease.

The Drive Train can waste energy too. Gears can be particularly wasteful if they are not precision made. Some form of belt drive may be best but be sure the belt doesn't slip, and that it is not overly tight. The drive ratio is very critical. You will want to experiment to see which drive ratio gives the best results with your car. It may be that different ratios are best for different sun conditions. You may want to be able to quickly change ratios to do best on a cloudy day from that ratio that is best on a sunny day.

The weight of the car is a very important design consideration. Since the car is probably accelerating most of the run, the weight is more important than if the car was traveling at a constant speed. Also, the weight is a direct multiplier on rolling resistance. Twice the weight means twice the rolling resistance for the same wheels, tires, and bearings. So use light-weight materials, built-up construction, or other lightening techniques. Remember though, that there must be enough weight on the drive wheels so that they don't spin.

4. **MATERIALS:**

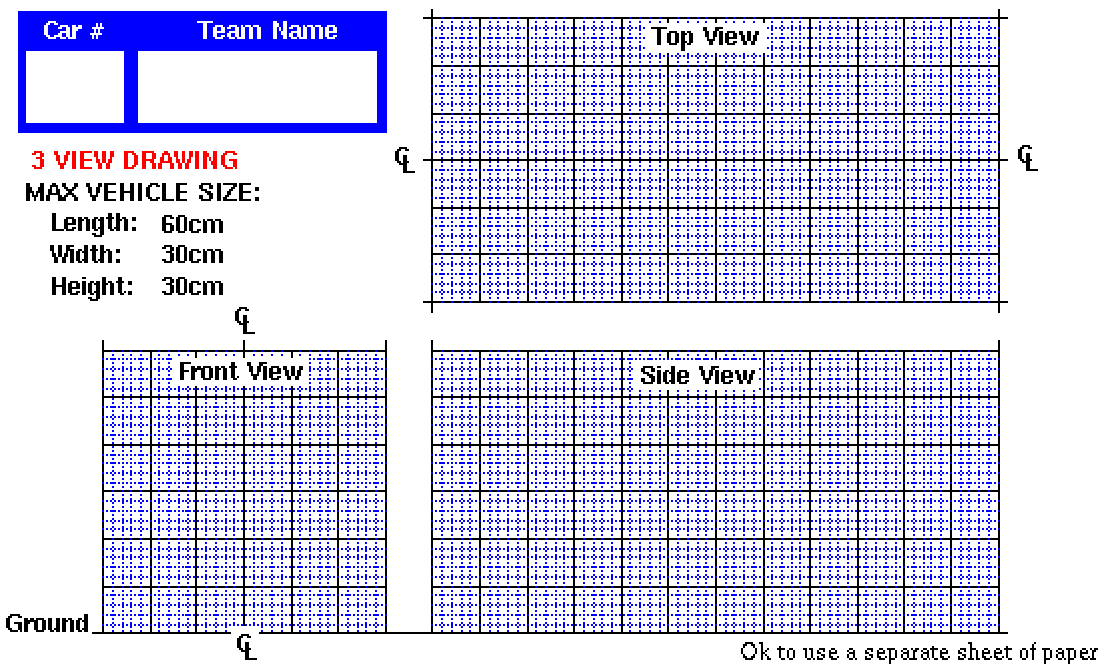
Take a look at each of the materials sections in Units 1 through 8 for ideas.

5. **EXPERIMENTS & INVESTIGATIONS:**

Preliminary Design Review Presentation Prep

Fill out this form and prepare a 5 minute presentation on your design to a group of peers or your class - make the presentation and field questions (this is the preparation stage for the H2 Presentation).

1. **DRAWINGS:**



2. **COMPONENTS:**

A. **TRANSMISSION:**
- What type:
- What materials:
- Who will build:
- How will we test:

B. **CHASSIS**:
- What type:
- What materials:
- Who will build:
- How will we test:

C. **WHEELS & BEARINGS**:
- What type:
- What materials:
- Who will build:
- How will we test:

D. **BODY SHELL & ARRAY**: Presented By:_
- What type:
- What materials:
- Who will build:
- How will we test:

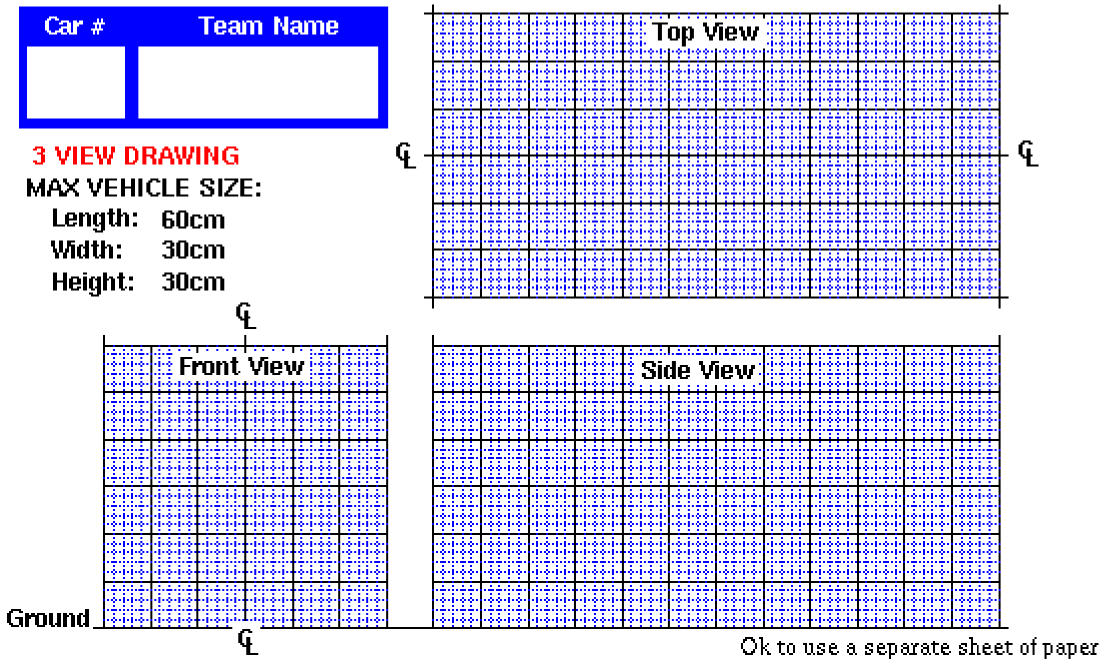
3. **MATERIALS**:
- Any special Materials to be used:
- Any special Processes to be used:

10. Design Review Presentation

FINALIZE DESIGN REVIEW PRESENTATION

Fill out this form and prepare a 5 minute presentation on your design for the H2 Presentation – prepare to make the presentation, assign speakers and parts, and include time to field questions.

1. **DRAWINGS:**



2. **COMPONENTS:**

A. **TRANSMISSION:** Presented By: ________________
- What type:
- What materials:
- Who will build:
- How will we test:

B. **CHASSIS**: Presented By:_ _______________
- What type:
- What materials:
- Who will build:
- How will we test:

C. **WHEELS & BEARINGS**: Presented By: ________________
- What type:
- What materials:
- Who will build:
- How will we test:

D. **BODY SHELL & ARRAY:** Presented By: _______________
- What type:
- What materials:
- Who will build:
- How will we test:

E. **MATERIALS**:
- Any special Materials to be used:
- Any special Processes to be used:

11. Construction of Vehicles

1. **PURPOSE:**

Once you have constructed your car and performed some testing you will want to make adjustments to improve performance. Apply what you have learned in the investigations and prototypes you have constructed to solve problems. Get the whole team involved in brainstorming solutions - even ask other teams or observe what others have done to solve your problems. Remember, your car must be ready for the race so time is a critical consideration.

2. **IDEAS:**

Some ideas for this process.
- Try to identify the source of the problem.
- Compare your car to prototypes you have constructed.
- Evaluate how long it will take to make corrections.
- List out your options with pros - cons & time then determine what to do, and do it.
- Re-test your car after any change to see what the change did.
- Only make one change at a time.

3. **CONCEPTS:**

a. ***Observation***
During your testing, make notes of what works best. Test the car on the track (or a close replica) attached to the guide string and make what adjustments you are able to in the current design. Look for parts that are rubbing, alignment of wheels, loose wires or parts, or weak points in the structure. Watch what happens as the car goes down the line and then isolate what the problem is that needs to be corrected. Work as a team and be sure and evaluate completely all input from every team member.

b. ***Determine Options for Correction***
Once you have identified the problem brainstorm the options for fixing it. Take advantage of the prototypes you built during the first few weeks of the project, and the things you learned during the design reviews. Make a complete list of the options you have including the difficulty of each, how much time it will take and the availability of parts/materials. Then as a team, start eliminating them until you get the top one or two then as a team decide which approach to take.

c. ***Make the change and evaluate results***
Once you make a change to your car, re-test it and find out if the fix improved the car or not. Try to do the test exactly the same way as before and make sure nothing else went wrong during the rework. You should only do one thing at a time so you know what is affecting the performance of your car. As you optimize the car, you will be more successful in the race.

4. **MATERIALS:**

o Not Applicable.

5. **EXPERIMENTS & INVESTIGATIONS:**

None.